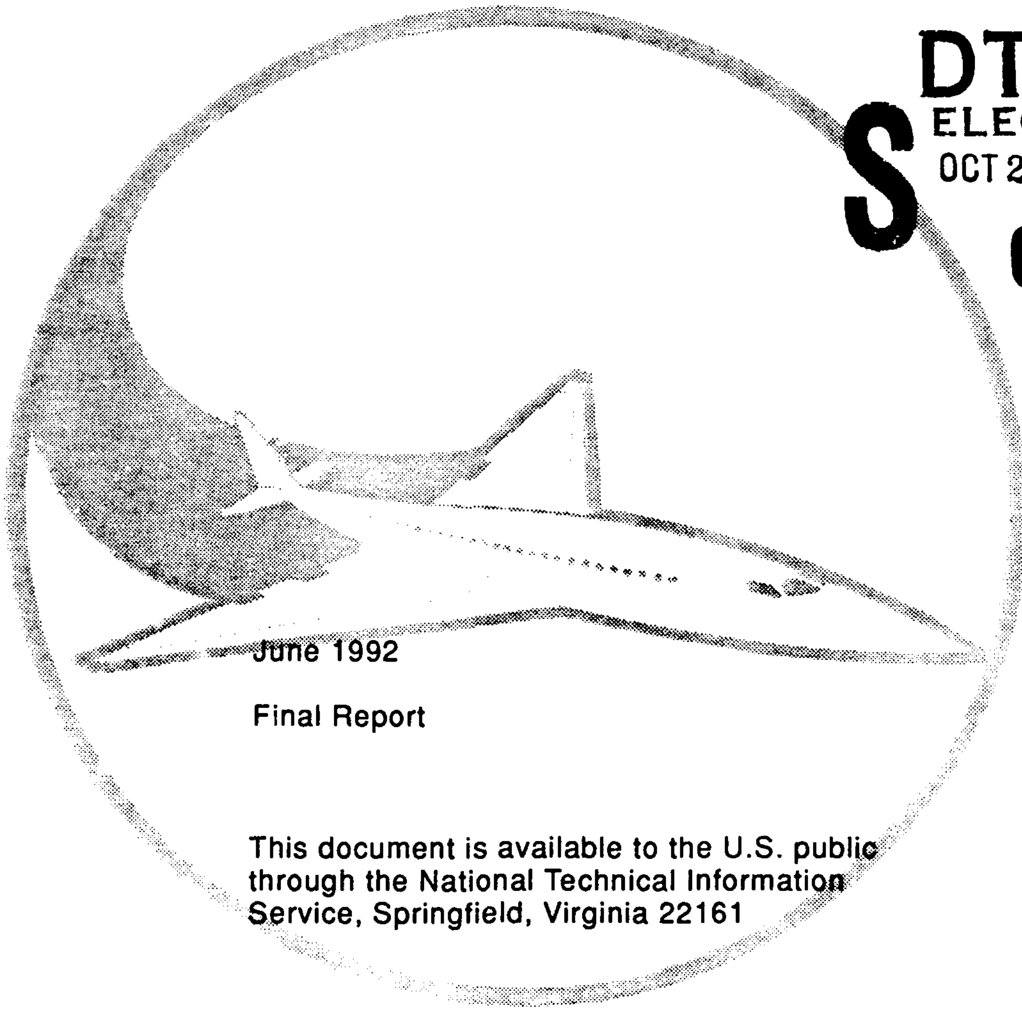
DOT/FAA/CT-91/5

FAA Technical Center
Atlantic City International Airport
N.J. 08405

Current Nondestructive Inspection Methods for Aging Aircraft



June 1992

Final Report

This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

This document is disseminated under the sponsorship of the U. S. Department of Transportation in the interest of information exchange. The United States Government assumes no liability for the contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the objective of this report.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/CT-91/5		

4. Title and Subtitle

Current Nondestructive Inspection Methods For Aging Aircraft

5. Report Date

June 1992

6. Performing Organization Code

7. Authors George Ansley, Stephen Bakanas, Maurice Castronuovo, Ted Grant, Frank Vichi

8. Performing Organization Report No.

9. Performing Organization Name and Address

Galaxy Scientific Corporation
71 Cantillion Blvd
Mays Landing, NJ 08330

10. Work Unit No. (TRAIS)

11. Contract or Grant No.

DTFA03-89-C-00043

12. Sponsoring Agency and Address

U.S. Department of Transportation
Federal Aviation Administration
Technical Center
Atlantic City International Airport, NJ 08405

13. Type of Report and Period Covered

Final Report

14. Sponsoring Agency Code

ACD-210

15. Supplementary Notes

COTR: Nelson Miller, FAA Technical Center
Technical Monitor: Dave Galella, FAA Technical Center

16. Abstract

This report identifies and describes current methods used during the nondestructive inspection (NDI) of commercial transport aircraft for structural damage. The six most prevalent NDI methods identified are visual, eddy current, radiography, ultrasonic, penetrant, and magnetic particle. The physical principles, generalized performance characteristics, and typical applications associated with each method are described. In addition, descriptions of specific airframe and engine inspection practices are also presented.

17. Key Words

NDI, NDT, NDE	Nondestructive Inspection
Visual	Eddy Current
Dye Penetrant	Ultrasonic
Airframe	Radiography
Turbine Engine	Magnetic Particle

18. Distribution Statement

Document is available to the public through the
National Technical Information Service
Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	132	

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

EXECUTIVE SUMMARY

This report identifies and describes the most prevalent nondestructive inspection methods, equipment, and procedures currently in use at aircraft maintenance facilities for the inspection of commercial transport aircraft.

The report is divided into four sections: Introduction, Nondestructive Inspection Methods, Aircraft Inspection Applications and supporting Appendices.

Introduction. This section contains an overview of aging aircraft and related issues. It also provides a brief description of the commonly used NDI methods.

Nondestructive Inspection Methods. This section describes specific details of the six major NDI methods used for aircraft inspection. These methods are visual, eddy current, radiographic, ultrasonic, penetrant, and magnetic particle. Each method includes a general description, the type of defects capable of being detected, method characteristics, and specific equipment manufacturers.

Aircraft Inspection Applications. This section is divided into the subsections of airframe inspections and jet engine inspections. Each subsection describes flaws generally encountered in those areas and the appropriate methods and procedures to detect them.

Appendices. The appendices include examples of actual procedures to inspect aircraft using the eddy current, ultrasonic and radiographic methods.

INTRODUCTION

BACKGROUND.

An increased demand for commercial aircraft has forced air carriers to operate existing aircraft beyond their original economic design life. Consequently, the average age of the U.S. commercial fleet has risen steadily from 4.6 years in 1970 to 12.7 years in 1989. If this trend is maintained, 60 percent of the current fleet will exceed their economic design life by the end of this decade.

Chronological age alone may not reflect the condition of the airplane structure. The number of flights, the cumulative flight time, environmental exposure, and usage patterns also play a role. Together, however, these factors tend to correlate well with chronological age, and structural problems such as fatigue cracking, corrosion, and disbonding are more likely to be encountered in high-time aircraft.

Prior to 1978, the Federal Aviation Administration (FAA) maintained that aircraft structure be designed according to fail-safe requirements. This required that sufficient redundancy be designed into an aircraft structure such that if a major structural element were to fail, the surrounding structure would safely bear the additional load. Since that time, the fail-safe design requirement has been augmented by damage tolerance criteria.

Damage tolerance maintains that an aircraft remain airworthy despite the possibility of containing subcritical cracks and flaws. This philosophy recognizes the impossibility of establishing complete structural redundancy throughout the aircraft. Accordingly, continued airworthiness of damage tolerant aircraft strongly depends upon the implementation of inspection programs capable of detecting cracks and flaws prior to reaching their critical size. To further strengthen the maintenance and inspection procedures required to meet damage tolerance criteria, the FAA issued Advisory Circular (AC) 91-56 in 1981. This AC provides aircraft manufacturers and operators with guidelines for establishing Supplemental Structural Inspection Documents (SSIDs). SSIDs provide a plan to maintain the continued airworthiness of older transport aircraft by meeting damage tolerant requirements. Through the SSID programs, aircraft that were originally designed fail-safe are essentially brought into conformance with the damage tolerance philosophy by means of updated inspection programs.

Because of the additional number of inspections directed by the SSID programs, there has been an increased emphasis placed upon the

importance of nondestructive inspection (NDI). The importance of NDI stems from its ability to determine structural integrity with minimal aircraft tear-down, disassembly, downtime and loss of revenue.

PURPOSE.

The purpose of this report is to identify and describe the most prevalent NDI methods, equipment and procedures currently in use at aircraft maintenance facilities for the inspection of commercial transport aircraft.

SCOPE.

This report describes the six most prevalent NDI methods used to inspect commercial aircraft. Also included are sections describing NDI procedures for specific airframe and engine applications. It is hoped that interested parties will seek additional information in more extensive works on NDI.

METHODS OF INSPECTION. The principles underlying each method are described as well as the types of defects sought by the method and a listing of particular performance characteristics associated with that method. Also identified are examples of specific equipment used at inspection shops to accomplish the various inspection tasks.

Description of Methods. Brief descriptions of the six commonly used methods of NDI are listed below.

1. Visual - Visual inspection is the most common form of NDI and consists of viewing the area by the eye, with or without aid of a magnifying glass, borescope, light source, etc.

2. Eddy Current - Eddy current inspection is used to detect surface or near-surface cracks in metals, to detect thinning of metals due to corrosion and to sort metals or alloys and their heat treat conditions. High frequency eddy current techniques can be applied to airplane parts or assemblies where the defective area is accessible to contact by the eddy current probe. Low frequency techniques are used to detect cracks or corrosion on back surfaces or cracks in underlying structure. The inspection is performed by inducing eddy currents into a part and electronically observing variations in the induced field.

3. Radiographic - Radiographic inspection will show internal and external structural details of all types of parts and materials. It is usually used for the inspection of inaccessible areas in the airframe structure or thick sections which do not lend themselves to inspection through other NDI methods. It is accomplished by

transmitting an x-ray or gamma-ray beam through the part or assembly being tested. The transmitted beam impinges on radiographic film or detector and reveals anomalies. The structural details of the part or assembly will be shown by variations in density on film or a video display. Interpretation of the radiograph will indicate defects.

4. Ultrasonics - Ultrasonic inspection is suitable for the inspection of most metals, plastics, and composites for surface or subsurface defects. Ultrasonic inspection requires at least one surface of the part to be accessible in the vicinity of the area being inspected. The inspection of aircraft structure is accomplished by inducing ultrasonic waves into the part and picking up reflections of this sound from within the part. The detected ultrasonic reflections are electronically displayed on an oscilloscope for interpretation by the inspector.

5. Penetrant - Penetrant inspection is used to detect small cracks or discontinuities open to the surface that are not evident by normal visual inspection. Penetrant inspection can be used on most aircraft parts and assemblies accessible for its application. The inspection is performed by applying a liquid that penetrates into surface defects. Excessive penetrant is then removed from the surface and suitable developers are applied to draw the remaining penetrant from the defects. Visual indications at the surface are obtained by using fluorescent or dye-colored penetrants.

6. Magnetic Particle - Magnetic particle inspection will indicate surface or subsurface defects in ferromagnetic parts. It may be performed on assembled or disassembled parts. The test is accomplished by inducing an electromagnetic field in the part and applying a dry powder or liquid suspension of fluorescent or colored iron oxide particles. Local magnetic poles formed by defects in the part will attract the particles and indicate areas of discontinuities.

Defects Sought. The types of structural defects and failures associated with aircraft follow. These defects are attributable to aging effects caused by either time, flight cycles, service operating conditions, or combinations of these effects.

1. Fatigue Cracks - Fatigue cracks occur in parts that have been in service under repeated stress cycles. These cracks typically initiate where the design or surface conditions provide points of stress concentration. Such areas include sharp corners, seams, grinding cracks, and at fastener holes having poor surface finishes or sharp burrs. Undetected, fatigue cracks will eventually propagate through the part until failure occurs.

2. Corrosion - Corrosion occurs on almost all metals. Whether or not an aircraft experiences corrosion depends on its fabrication process and service conditions. Poor choices of surface treatments, protective coatings and dissimilar metal combinations greatly increase the likelihood of corrosion in those areas. In service, corrosion is caused by the presence of salts in moist air, or by some other abetment present in the chemical content of the water or elements in the metal.

3. Disbonds - In addition to riveting, many structural elements are joined by bonding processes. Weak or improper bonding can lead to immediate joint failure or, where rivets are present, higher than anticipated stresses which may cause fatigue cracking at those rivet sites. It is therefore necessary to detect all areas of disbonding as early as possible before such failure or fatigue cracking can occur.

Method Characteristics. Characteristics, including advantages and disadvantages, portability, rate of inspection, training required, and generalized descriptions of minimum detectable flaw size and probability of detection (POD) and false alarms, are provided for each of the six methods. Knowledge of these characteristics, coupled with an understanding of the theory of each method, will aid in the selection of a particular method for a given inspection. Table 1 lists the advantages and disadvantages of the prevalent methods of NDI. The method of inspection for a part will depend on several factors including accessibility, portability, type of defect sought, material of the part, and degree of sensitivity required.

Typical Equipment Used to Inspect Aircraft. A list of typical equipment used to inspect commercial transport aircraft is provided for each NDI method. For a more comprehensive list of equipment and manufacturers covering all industrial NDI applications, the reader is referenced to the annual Buyers Guide published in Materials Evaluation, the official journal of the American Society for Nondestructive Testing (ASNT).

AIRFRAME INSPECTIONS. In addition to the NDI method descriptions, this report identifies specific NDI applications concerning various aircraft subassemblies. These subassemblies include the fuselage, wings, empennage, control surfaces and landing gear. Many specific procedures pertaining to these areas are contained in the appendices.

JET ENGINE INSPECTIONS. Typical engine NDI routines including on-wing and off-aircraft inspections and monitoring are presented.

Table 1. Comparisons of Inspection Methods

METHOD	ADVANTAGES	DISADVANTAGES
Visual	• Inexpensive • Highly portable • Immediate results • Minimum training and part preparation	• Surface defects only • Generally only larger defects • Misinterpretation of scratches
Eddy Current	• Detects surface and subsurface flaws • Portable • Immediate results • Sensitive to small defects • Thickness sensitive • Moderately fast	• Surface must be accessible to probe • Rough surfaces interfere with test • Metals only • Skill and training required • Time consuming for large areas
X-ray Radiography	• Detects surface and internal flaws • Can inspect hidden areas • Permanent test record obtained • Minimum part preparation	• Very expensive • Highly sensitive to flaw orientation • High degree of skill and experience required for exposure and interpretation • Depth of defect not indicated • Safety hazard
Isotope Radiography	• Portable • Less expensive than x-ray • Detects surface and internal flaws • Can inspect hidden areas • Permanent test record obtained • Minimum part preparation	• Must conform to federal and state regulations for handling and use • Depth of defect not indicated • Highly sensitive to flaw orientation • High degree of skill and experience required for exposure and interpretation • Safety hazard
Ultrasonic	• Portable • Detects surface and subsurface flaws • Sensitive to small defects • Immediate results • Little part preparation • Wide range of materials and thicknesses can be inspected	• Surface must be accessible to probe • Rough surfaces interfere with test • Highly sensitive to sound beam-defect orientation • High degree of skill required to set up and interpret • Couplant usually required
Penetrant	• Portable • Inexpensive • Sensitive to very small defects • Immediate results • Minimum skill required	• Surface must be accessible • Rough surfaces interfere with test • Part preparation, such as removal of finish and sealants, required • High degree of cleanliness • Direct visual detection of results required
Magnetic Particle	• Portable • Inexpensive • Sensitive to small defects • Immediate results • Moderate skill required • Detects surface and subsurface flaws • Relatively fast	• Surface must be accessible • Rough surfaces interfere with test • Part preparation, such as removal of finish and sealants, required • Field orientation affects flaw detection • Ferromagnetic materials only • Part must be demagnetized after test

NONDESTRUCTIVE INSPECTION METHODS

VISUAL.

DESCRIPTION OF METHOD.

General. Visual inspection is the oldest and most common form of NDI used to inspect aircraft. The physical principle behind visual inspection is that visible light is reflected from the surface of the part to the inspector's eyes. By observing the appearance of the part, the inspector can infer its condition. Visual inspection is a quick and economical method of detecting various types of defects before they cause failure. Its reliability depends upon the ability and experience of the inspector. The inspector must know how to search for critical flaws and how to recognize areas where failure could occur. The human eye is a very discerning instrument and with training, the brain can interpret the slightest indications that point to defects.

Optical devices are available to aid the naked eye in visual inspection and flaw detection. This equipment can be used to magnify defects that could not be seen by the unaided eye or to permit inspection of otherwise hidden areas.

Equipment. Visual inspection is often conducted using a strong flashlight, a mirror with a ball joint, and a magnifying aid. Magnifying aids range in power from 1.5x to 2000x. Fields of view typically range from 3.5 to 0.006 inches with resolutions ranging from 0.002 to 0.000008 inches. A 10x magnifying glass is recommended for positive identification of suspected cracks. Other inspection methods, such as penetrant or eddy current, can also be used to verify questionable indications.

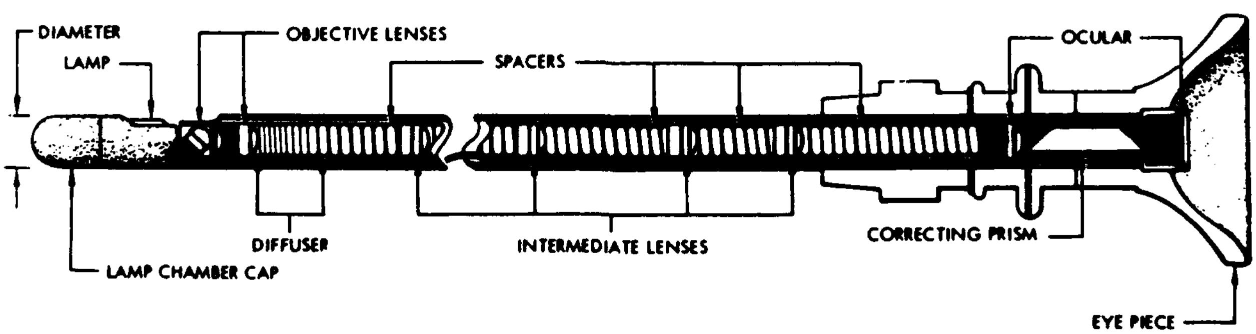


FIGURE 1. TYPICAL BORESCOPE CONSTRUCTION

1. Borescopes - A borescope (see figure 1) is a rigid rod that allows an inspector to see into inaccessible areas by transmitting an

image from one end of the scope to the other. They can be inserted into openings, such as an igniter hole in an engine, to facilitate inspection of components deep inside. This is accomplished by forming an image of the viewing area with an objective lens. That image is then transferred along the rod by a system of intermediate lenses. Finally, the image arrives at the ocular, which creates a viewable virtual image. The ocular can be focused for comfortable viewing so that the image appears anywhere from a few inches to an infinite distance away. Borescopes typically range from 0.25 to 0.50 inches in diameter and can be as long as 6 feet in length.

Borescopes often incorporate a light near the objective lens to illuminate the viewing area. Their construction falls into four types, depending on the field of view (see figure 2).

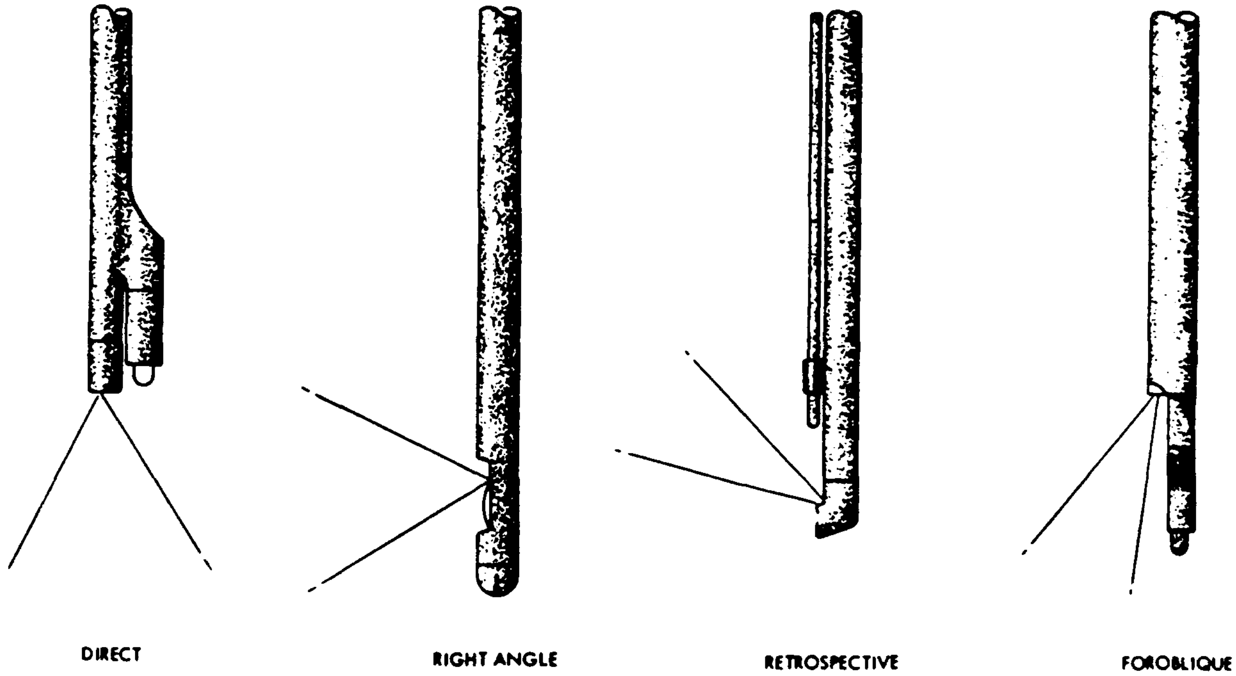


FIGURE 2. BORESCOPES DESIGNED FOR INSPECTING VARIOUS GEOMETRIES

Forward or direct-vision scopes provide vision directly forward from the tip of the borescope.

Right angle scopes give a field of view to the side of the scope, extending in an angular field from about 55 to 125 degrees from the axis of the scope.

Retrospective scopes provide vision slightly rearward, from about 110 to 150 degrees from the axis.

Foroblique scopes allow vision forward and to the side in a field extending from about 0 to 55 degrees.

2. Fiberscopes - Fiberscopes are bundles of fiber optic cables that transmit light from end to end. They are similar to borescopes, but they are very flexible. They can be inserted into openings and curled into otherwise inaccessible areas. They also incorporate light sources for illumination and devices for bending the tip in any direction desired. Like the borescope, fiberscope images are formed at an ocular or eyepiece.

3. Video Imaging Systems - Video imaging systems or "videoscopes," consist of tiny charge coupled device (CCD) cameras at the end of a flexible probe. Borescopes, fiberscopes and even microscopes can be attached to video imaging systems. These systems consist of a camera to receive the image, processors, and a monitor to view the image. The image on the monitor can be enlarged or overlaid with measurement scales. Images can also be printed on paper or stored digitally. In this manner, a permanent record of the inspection can be obtained.

Indications. Before attempting a close, visual inspection of any part or area, it should be inspected for corrosion. Any corrosion found should be examined to determine its extent and severity. The first appearance of corrosion on unpainted aluminum surfaces is usually in the form of white powder or spots. Corrosion on painted, plated, or clad surfaces is often characterized by a scaly or blistered appearance, or a discoloration of the paint. Corrosion on aluminum alloys or plated steel is characterized by a dulling or pitting of the area, sometimes with white or red deposits.

One should also examine the area for deformed or missing fasteners. These indicate possible structural failure and should be marked for subsequent replacement. Areas around fasteners should be carefully inspected, as cracks often start at fastener holes.

When searching for surface cracks, one should direct a strong light at an angle to the surface under inspection (see figure 3). A 10x magnifying glass can be used to confirm the existence or extent of a crack.

Part Preparation/Safety. Visual inspection does not require part disassembly or removal. However, access to the desired area must be acquired. Consequently, some fairing or access panel removal and limited adjacent equipment disassembly may be required. In addition to this, the part must be adequately stripped and cleaned so that all indications will be visible.

DEFECTS SOUGHT. Visual inspection is a fast, inexpensive NDI method that can be used on any material. Principal applications consist of:

Flaw Detection. Typical flaws sought during visual inspection include surface cracks, porosity and other defects in casted parts. Weld defects such as cracks, blow holes, insufficient penetration, lack of fusion, and other discontinuities at the surface can be found. Forgings, such as turbine shafts and rotors, can also be inspected during disassembly for defects.

Corrosion Detection. Surface corrosion, exfoliation, pitting, and intergranular corrosion can be detected visually when proper access to the inspection area is obtained.

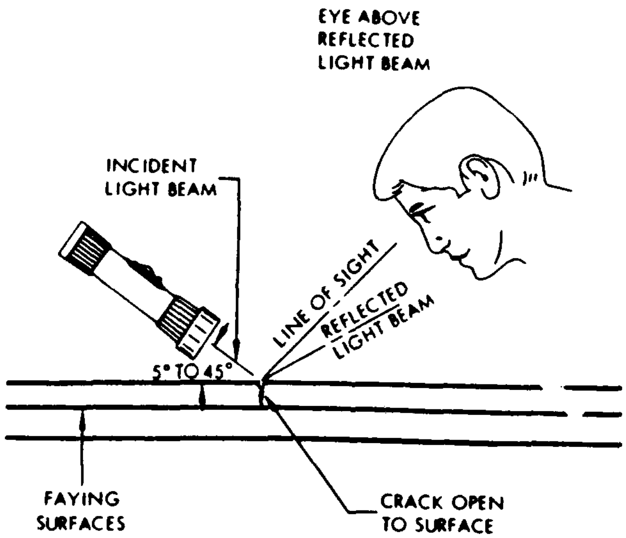


FIGURE 3. CRACK INSPECTION USING REFLECTED LIGHT TO ENHANCE CONTRAST OF CRACKED SURFACE

METHOD CHARACTERISTICS.

Minimum Detectable Flaw Size. The minimum size flaw that can be detected visually varies according to inspection aids used. More magnification will allow smaller defects to be detected, but will greatly increase inspection time and operator fatigue.

Advantages. The primary advantages of visual inspection include its ability to be performed quickly and inexpensively without the need of complicated equipment. Only little training is required and typically no special safety precautions need to be taken. Where

necessary, permanent records can be obtained by photography or digital imaging and storage.

Disadvantages. The disadvantage of visual inspection is that the surface to be inspected must be relatively clean and accessible to either the naked eye or an optical aid such as a borescope. Typically, visual inspection lacks the sensitivity of other surface NDI methods.

Probability of Detection/Probability of False Alarm. Probability of detection (POD) for small defects is lower than with other methods. Scratches can be confused with cracks and usually other inspection methods can be used to confirm visual indications.

Inspection Rate. Visual inspection yields immediate results. Magnification aids can slow down inspection considerably and are typically used in critical or problem areas only.

Training. Simple visual testing can be performed with little training. Searching for flaws in critical parts, however, requires a high degree of experience and skill.

Portability. All visual inspection equipment is highly portable.

TYPICAL EQUIPMENT USED TO INSPECT AIRCRAFT. There are three categories of visual aids used by inspectors to assist or supplement visual inspections. These are magnification, mirrors, and borescopes.

Magnification (typically 5x or 10x magnifying glasses) and mirrors are generally selected by inspectors to suit personal preferences and the requirements of the inspection.

Rigid borescopes and fiberscopes in a variety of sizes and designs are common inspection tools at aircraft maintenance facilities where they are primarily used for engine inspections.

The following are some of the manufacturers of rigid borescopes and flexible fiberscopes used to inspect aircraft:

ACMI/Circon/Fujinon
ITI - Instrument Technology, Inc.
Lennox Instruments, Inc.
Machida, Inc.
Olympus Corp.
Wolf Medical Instruments

The following are manufacturers of videoscopes:

- ITI - Instrument Technology, Inc.
- Olympus Corp.
- Welch Allyn, Inc.

EDDY CURRENT.

DESCRIPTION OF METHOD.

General. When an electrically conductive material is exposed to an alternating magnetic field that is generated by a coil of wire carrying an alternating current, eddy currents are induced on and below the surface of the material (see figure 4). These eddy currents, in turn, generate their own magnetic field which opposes the magnetic field of the test coil. This magnetic field interaction causes a resistance of current flow or impedance in the test coil. By measuring this change in impedance, the test coil or a separate sensing coil can be used to detect any condition that would affect the current-carrying properties of the test material.

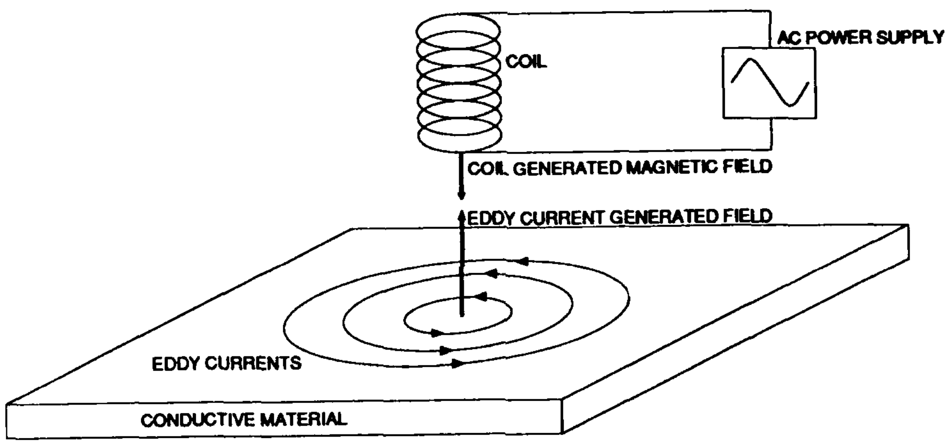


FIGURE 4. EDDY CURRENTS INDUCED IN CONDUCTIVE MATERIALS BY VARYING MAGNETIC FIELDS

Eddy currents are sensitive to:

1. Changes in electrical conductivity. The electrical conductivity of a metal may vary with its chemistry (alloy) or with the heat treatment of the part.

2. Changes in magnetic permeability (ability of a material to be magnetized). The magnetic steels used in aircraft structure generally have high permeability values. Eddy current instrumentation is very sensitive to any change in permeability and the normal permeability variations in a typical steel part may cause erratic and confusing readings on an eddy current instrument. As a rule, eddy current testing is recommended for steel parts only when other NDI methods such as penetrant or magnetic particle are not feasible.

3. Geometry - The shape or geometry of a part may affect eddy current readings. For example, the readings will be affected if the part is thin and the eddy current field completely penetrates the part. Similarly, the readings will be affected if the coil gets too close to an edge (edge effect).

4. Defects - Cracks, inclusions, corrosion and porosity are typical defects detectable by eddy current. Laminar cracks lying parallel with the inspection surface are detectable with eddy current.

Most modern eddy current instruments in use by the airlines are relatively small and battery powered. They can be used for a wide variety of test applications by changing the probe containing the coil and/or changing the test frequency.

In general, surface defect detection is accomplished with probes containing small coils (for example, 0.10 inch diameter) at a relatively high frequency. High frequency eddy current (HFEC) is generally considered 100 kHz and above.

Low frequency eddy current (LFEC) is used to penetrate deeper into a part to detect subsurface defects or cracks in underlying structure. The lower the frequency, the deeper the penetration. LFEC is generally considered between 100 Hz and 50 kHz.

The generation of LFEC requires relatively large coils and the detectable crack size for subsurface or second layer cracks is significantly larger than can be detected on the surface with HFEC. For example, a 0.5 inch diameter coil operating at 500 Hz might be used to detect a 1.0-inch long crack in an aluminum splice plate beneath a 0.2 inch thick aluminum skin. For comparison, a typical HFEC application might be performed at 250 kHz with a coil 0.10 inch diameter with the capability of detecting surface cracks on the order of 0.030 inch deep and 0.040 inches in length.

The test coil is contained in a probe or fixture that provides protection of the coil and lead wires to the eddy current instrument. Eddy current probes are available in innumerable configurations for various applications.

Early eddy current instruments used for aircraft inspection operated in the higher frequency ranges (i.e., 100 kHz to 3 MHz) and were used for surface crack detection. These instruments had a meter display that responded to changes in the voltage in the test coil. The application of low frequency test procedures in the late 1970's led to the development of stable, multi-frequency, battery-powered metered

instruments. These are the systems primarily used by the airlines today.

An improvement to the eddy current method came with the development of phase analysis instruments which provide both impedance and phase information. The information is displayed on an oscilloscope or LCD (liquid crystal display). This is the basis for impedance plane analysis techniques. Thus eddy current inspection has progressed to where it has become the most widely used NDI method in aircraft inspection.

Equipment. Eddy current instrumentation can range from simple, portable units with hand-held probes to fully automated systems. Each system, however, contains the following components:

1. A magnetic field source capable of inducing eddy currents in the part being tested. Generally, this is a coil housed in a probe, carrying alternating current. Various coil geometries are used for different test conditions.

2. A means of sensing the coil impedance changes produced by interaction of the eddy currents and the magnetic field produced by the coil. This sensor is either the exciting coil itself or, in a dual probe system, a separate receiving coil.

3. A means of measuring and displaying the changes of coil impedance.

Indications. Results from eddy current inspections are obtained immediately. Depending upon the type of instrument used, the results can be interpreted either by reviewing a meter deflection or a signal trace on a cathode ray tube. Metered types are typically used to detect changes in the amplitude of the impedance of the receiving coil. When using this type of metered, eddy current instrument, the inspector would first set up the instrument on a calibration block containing a crack of a known size. The inspector would zero the instrument on a part of the calibration block that is not cracked. Then, as the probe is positioned over the crack, the meter would deflect from the zero point. By adjusting a gain control, the inspector can have the needle deflect a predetermined distance for a crack of known size. Figure 5 illustrates the operation of a typical metered instrument. This type of instrument is relatively easy to use, although proper knowledge is required in the selection of the probe and frequency.

The other type of eddy current instrument currently used for aircraft inspection displays its results in planar form on a CRT screen. This

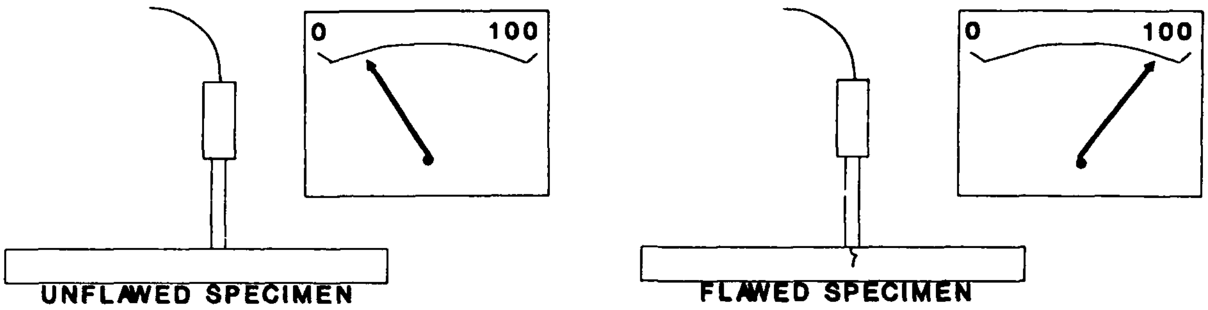


FIGURE 5. METER DISPLAY ILLUSTRATING THE AMPLITUDE OF A TYPICAL EDDY CURRENT SIGNAL

format allows both components of the coil's impedance to be viewed. One component consists of the electrical resistance due to the metal path of the coil wire and conductive test part. The other component consists of the resistance developed by the inducted magnetic field upon the coil's magnetic field, referred to as the inductive reactance. The combination of these two components on a single display is known as an impedance plane. During an inspection, if the test coil encounters a change in conductivity, an overall change in the impedance of the coil will occur and the result is a signal traced across the CRT. From the trace, the inspector can determine both relative amplitude and phase information. This phase data is significant because it allows the inspector to determine the relative depth of a surface or near-surface defect. Figure 6 shows an example of an impedance plane display. It should be noted that interpretation of an impedance plane display requires extensive knowledge of all eddy current principles and therefore, requires proper training.

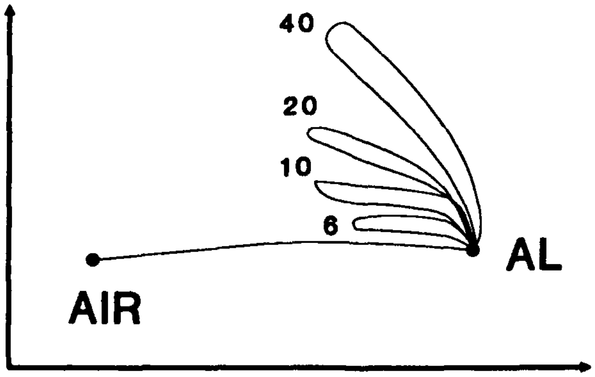


FIGURE 6. IMPEDANCE PLANE DISPLAY SHOWING THE PHASE, AS WELL AS THE AMPLITUDE, OF THE EDDY CURRENT SIGNAL. THIS DISPLAY ILLUSTRATES SIGNAL TRACES FOR SURFACE FLAWS OF 6, 10, 20, AND 40 MILS IN LENGTH.

Part Preparation/Safety. A major advantage of the eddy current method is that it requires only minimum part preparation. Reliable inspections can be performed through normal paint or nonconductive materials up to thicknesses of approximately 0.015 inch. Loose soils and materials that might abrade the probe should be removed.

DEFECTS SOUGHT. Eddy current testing is used extensively in aircraft maintenance inspection to detect cracks, heat damage, and corrosion thinning. The test is generally accomplished using variable frequency instruments with either a meter or impedance plane display.

Cracks. Eddy current inspection is used extensively for crack detection in aircraft structure during maintenance checks.

Corrosion. HFEC inspection is used to detect exfoliation corrosion around installed fasteners.

Thickness Measurement. Eddy current inspection is used while performing thickness measurements. It is accomplished by selecting a frequency that will properly penetrate the part under inspection and then comparing the impedance plane response of the part to a known calibrated thickness standard. A different response indicates a change in thickness.

Metal Spacing. In some cases a gap may separate two metal sheets or parts. The gap could be filled with air, a non-metallic shim, or a nonconductive layer. In some cases this gap must be held within close tolerances. It can be measured using eddy current with the same procedure as in the thickness measurement. One application is the measurement of the gap between the outer aluminum skin and inner titanium skin of an engine nose cowl inlet duct.

A description of specific applications of the eddy current method and other NDI methods may be found in the airframe inspection and jet engine inspection sections of this report.

METHOD CHARACTERISTICS.

Minimum Detectable Flaw Size. Flaw detection varies greatly with material and distance of the flaw from the surface. Surface flaws as small as a few thousandths of an inch can be detected in aluminum plate.

See appendix A for examples of specific eddy current techniques and detectable flaw sizes.

Advantages. The advantages of using the eddy current method are that it can detect surface and subsurface flaws, it is usually portable, and it provides immediate results. It is sensitive to small defects and thickness changes, it is low cost compared to other NDI techniques, it can produce a permanent record, and it is a moderately fast test procedure.

Disadvantages. The disadvantages of this method are that the surfaces to be inspected must be accessible to the eddy current probe, rough surfaces may interfere with the test, tests can only be performed on conductive materials, much skill and training are required, reference standards are needed for comparison, the depth of penetration is limited by the frequency of the probe, and it is a time consuming method for large areas.

Probability of Detection/Probability of False Alarm. Eddy current is one of the most sensitive and reliable methods for detecting surface and subsurface flaws. However, its application requires considerable skill. Trained and qualified personnel are required to achieve a high degree of reliability.

Inspection Rate. The inspection results are obtained in real-time using either a metered or impedance analysis instrument. Most eddy current inspections are directed at highly specific areas where the inspection can be accomplished rapidly. The method is not generally used on large areas where the inspection would be slow and require fixturing to assure complete coverage.

Training. Training is required to properly operate any eddy current system. The American Society for Nondestructive Testing has published Recommended Practice SNT-TC-1A "Personnel Qualification and Certification in Nondestructive Testing". These or similar guidelines are used by many airlines and airplane manufactures for the training and qualification of their inspectors. SNT-TC-1A requires approximately 80 classroom hours and 10 months experience for a person to be eligible to qualify for an ASNT Level II eddy current certification.

Portability. Most eddy current inspection systems are portable. Approximate weight of these systems ranges from 2 to 20 lbs.

TYPICAL EQUIPMENT USED TO INSPECT AIRCRAFT.

General Purpose Instruments. High frequency eddy current inspection procedures are used for the detection of defects that break the surface being inspected. Low frequency procedures are used for detecting subsurface defects or defects in a second layer. The

following are portable battery powered eddy current instruments used by the airlines for a wide variety of flaw detection applications:

Model	Manufacturer
Defectometer 2.164 and 2.835 Very High Frequency Meter Display	Forster Instruments
Defectoscop S-2.830 and Defectoscop SD-2.832 Low and High Frequency Impedance Plane Display	Forster Instruments
Halec MK II High Frequency Meter Display	Hocking NDT Ltd.
Super Halec Low Frequency Meter Display	Hocking NDT Ltd.
Locator UH High Frequency Meter Display	Hocking NDT Ltd.
AV-100 Series High and Low Frequency Impedance Plane Display	Hocking NDT Ltd.
ED 520 High Frequency Meter Display Small portable instrument widely used by the airlines.	Magnaflux Corp.
ED-800 High and Low Frequency Impedance Plane Display	Magnaflux, Corp.
Elotest B-1 High and Low Frequency Impedance Plane Display	ESR/Magnaflux Corp.

Nortec 19 High and Low Frequency Impedance Plane Display	Staveley Instruments, Inc.
Nortec - 23 ST High and Low Frequency Impedance Plane Display	Staveley Instruments, Inc.
MIZ-10, 10A and 10B High and Low Frequency Meter Display Versatile Multi-Frequency Instrument widely used by the airlines.	Zetec, Inc.
MIZ-20 and 20A High and Low Frequency Impedance Plane Display	Zetec, Inc.

Rotating Bolt Hole Inspection Instruments. The instruments in this category are designed for use with power driven rotating eddy current probes, such as those used for bolt hole inspection. The read-out is on a CRT or LCD display. There are several general purpose impedance plane eddy current instruments that can be used with rotating probes. The instruments listed below are designed specifically to be used with rotating probes. They are supplied with a variety of power driven probe "guns" or handles and operate at high frequency on battery power.

Model	Manufacturer
RECHII	Staveley Instruments, Inc.
Rototest	Electro-Spezial-Rohmann Gmbh
Defectoscop D 2.831	Forster Instruments

Conductivity Instruments. The following instruments are designed specifically for measuring the electrical conductivity of non-ferrous metals. Instruments marketed in the United States read directly in I.A.C.S. (International Annealed Copper Standard) units. These instruments are all battery powered.

Model	Manufacturer
Sigmatest 2.067 Meter Readout	Forster Instruments
FM-120 Meter Readout	Magnaflux Corp.

FM-140 Digital Readout	Magnaflux Corp.
MIZ-6 Meter Readout	Zetec, Inc.
Nortec-17 Digital Readout	Staveley Instruments, Inc.
Verimet 4900 Digital Readout	K.J. Law Engineers, Inc.

RADIOGRAPHIC.

DESCRIPTION OF METHOD.

General. Radiographic inspection is a nondestructive method of inspecting materials for surface and subsurface discontinuities. The method utilizes radiation in the form of either x-rays or gamma rays, which are electromagnetic waves of very short wavelength. The waves penetrate the material and are absorbed depending on the thickness or the density of the material being examined. By recording the differences in absorption of the transmitted waves, variations in the material can be detected. The variations in transmitted waves may be recorded by either film or electronic devices. The method is sensitive to any discontinuities that affect the absorption characteristics of the material.

X-rays are generated in a vacuum tube when high energy electrons are stopped by striking a high density target as depicted in figure 7. The electrons are generated by passing current through a filament in the negatively charged cathode of the x-ray tube. They are accelerated toward the target by applying a large voltage differential from the cathode to the anode where the target is embedded.

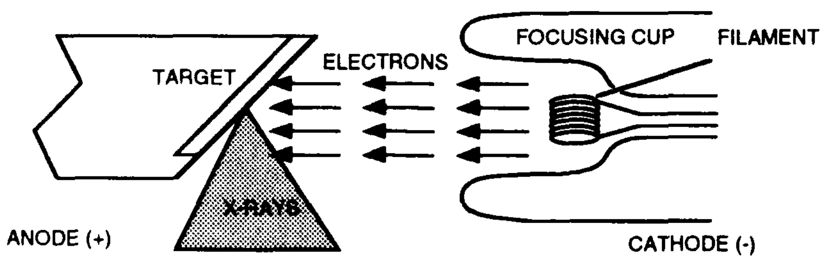


FIGURE 7. ESSENTIAL ELEMENTS FOR PRODUCING X-RAYS

The higher the energy of the emitted x-rays, the greater is their penetrating power. The maximum energy of the x-ray beam is proportional to the energy of the electrons, which in turn is proportional to the voltage applied across the tube. The x-rays produced form a spectrum of energies with the maximum energy limited by the voltage across the tube. That energy is expressed in thousands of electron volts (kV) or millions of electron volts (MeV) and represents the maximum energy of the beam.

The number of x-rays being emitted is a function of the number of electrons impinging on the target. The number of electrons flowing through the tube is measured in milliamperes (mA) and is referred to

as the tube current. The number of electrons generated is controlled by the amount of current applied to the filament in the cathode.

The current multiplied by the time the tube is on is called the exposure and represents the total number of x-rays impinging upon the part. The energy of the x-ray beam determines the penetrating power. The exposure, energy, and absorption characteristics of the material determine how many x-rays will reach the recording medium.

Gamma rays have the same characteristics as x-rays but they are generated during the decay of radioisotopes. The energy and quantity of rays being emitted cannot be varied since they are a function of the radioisotope and its activity. Each isotope has its own fixed energy and penetrating power. Its activity is measured in Curies and is a function of its disintegration activity. Its activity diminishes with time as the material decays. The decay rate is expressed as half-life which is the time for the isotope to decay to 50 percent of its original activity. Because isotopes are gamma ray emitters they do not need any external energy for power. They are generally small and portable, although some of the protective shielding may be rather cumbersome, especially for large sources. Isotopes have an advantage of being able to be placed into small areas not accessible to tubes.

Isotopes present a greater health hazard than x-rays because they cannot be shut off. Consequently, there are more regulatory controls put on their use and transportation than on x-ray tubes. They are further regulated by allowing only certified personnel to possess and work with them.

Equipment.

1. X-ray - X-ray equipment comes in a wide range of capabilities, which are described here.

a) Energy Output. Output energies of x-ray equipment can vary from 100 kV units used for x-raying thin aluminum, oil paintings, etc. to 8 MeV systems for 9 inch thick steel parts or greater. The bulk of x-ray work is done in the 200 to 400 kV range with a 10 mA output. The higher the energy output, the more shielding that is required and the more costly the containment room becomes.

b) Exposure Rooms. In order to protect anyone in the area, most x-rays are performed in enclosed rooms lined with lead, or made with thick concrete walls. The amount of protection needed is a function of the energy and exposures factors. With small energy sources, exposures can be made in a closed aircraft hangar provided it is evacuated and radiation is monitored and maintained below specified

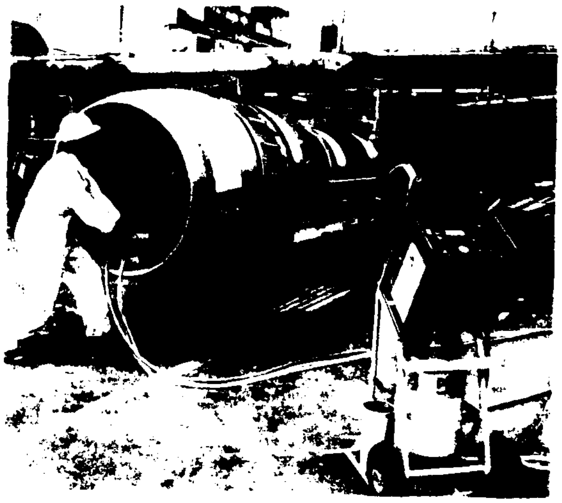


FIGURE 8. ENGINE INSPECTION USING A 160 kV METAL CERAMIC X RAY UNIT
Courtesy of Philips GmbH

FIGURE 9. INSPECTING THE UNDERCARRIAGE OF AN A300 AIRBUS
Courtesy of Philips GmbH

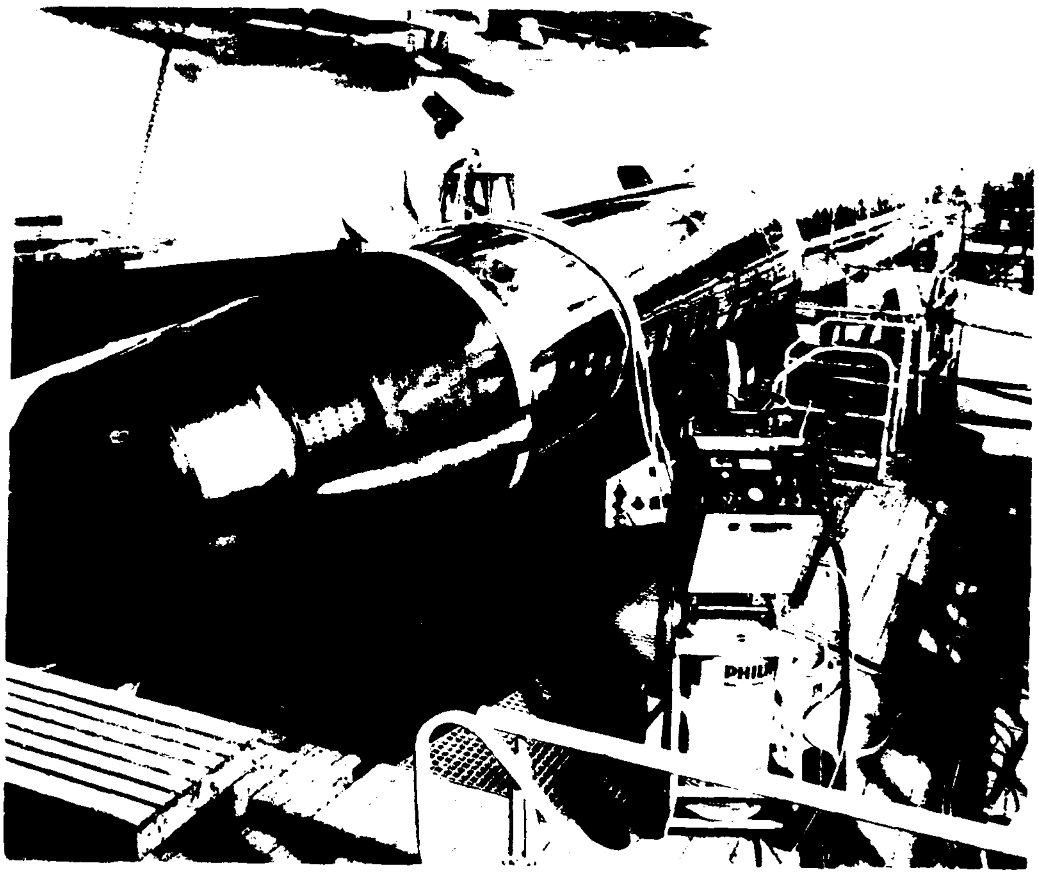


FIGURE 10. INSPECTING ENGINE MOUNT COMPONENTS FOR A BOEING 727 USING A MOBILE 160 kV X-RAY SYSTEM
Courtesy of Philips GmbH

levels. Figures 8 through figure 10 show various applications of x-radiography in a hangar environment. In production applications,

either enclosed rooms or small cabinets housing just the x-ray machine and the part are used.

c) Types of Tubes. There are many different types of tubes used for special applications. The most common is the directional tube which emits radiation perpendicular to the long axis of the tube in a cone of approximately 40 degrees. A group of these tubes are shown in figure 11.

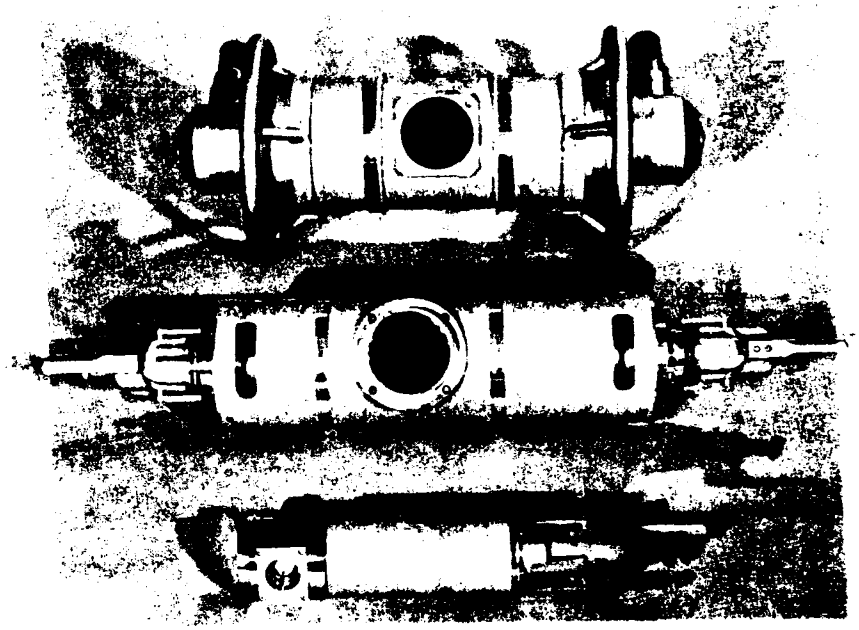


FIGURE 11. DIRECTIONAL X-RAY TUBES EMIT X-RAYS IN A NARROW CONE, PERPENDICULAR TO THE AXIS OF THE TUBE
Courtesy of Rich. Seifert & Co.

Another type of tube is the panoramic tube which emits x-rays in a complete 360 degree circle. This is very advantageous for x-raying girth welds on jet engine cases as it allows the complete weld to be examined with one exposure. Figure 12 shows a case being x-rayed by a panoramic tube.

Most tubes are limited on how small they can make the focal spot or area on the target from which the x-rays are emitted. The smaller the focal spot the sharper the image that is generated. Special "microfocus tubes" have focal spot sizes on the order of 50 microns.

They have very limited x-ray output and need long exposures but they do allow images to be enlarged by geometrical placement and have exceptional resolution of detail. Because of the damage done to the target, targets must be replaced periodically. This is especially true when the source is used with high current rates. Consequently, the tubes are normally removable, that is, they may be taken apart and the target may be replaced. This means that a vacuum system must be included to re-establish the vacuum in the tube. Figure 13 shows a microfocus x-ray system being used to detect cracks in jet engine burner cans. This particular tube is sealed and does not require a vacuum system.

FIGURE 12. PANORAMIC X-RAY TUBES EMIT X-RAYS IN A 360 DEGREE CIRCLE ABOUT THE TUBE
Courtesy of Philips GmbH

FIGURE 13. A MICROFOCUS X-RAY SYSTEM USED TO INSPECT A JT8D ENGINE BURNER CAN

d) Automatic Systems. When a series of similar parts are to be inspected, the parts handling portion and exposure parameters of the process may be automated. Real-time imaging systems are usually used with these systems. These real-time systems consist of radiation detection devices that convert x-ray energy into light energy and then use a video system to display the images. This allows image manipulation to be used for detail enhancement. If enough parts are inspected, the cost of the equipment can be absorbed by the savings in x-ray film and time.

e) Computed Tomography (CT Scanning). Advanced uses of radiography are being made with the aid of computers and high powered algorithms to manipulate data. By scanning a part from many directions in the same plane, a cross-sectional view of the part can be generated and the internal structure may be displayed in a two dimensional view. Figure 14 shows a cross-sectional view of a jet engine turbine blade made in such a manner. The tremendous advantage

of this method is that internal dimensions can be measured very accurately to determine such conditions as wall thinning, size of internal discontinuities, relative shapes, and contours. More advanced systems can generate three dimensional scans when more than one plane is scanned. Presently, CT scanning is extremely costly and scanning is time consuming. However, this technology has been applied to detect wall thinning in turbine blades.

2. Radioisotopic Sources - Radioisotopes provide very portable sources that can be used to generate radiographs where x-ray sources cannot be placed. An example of this is shown in figure 15 where the internal structure of the engine is being radiographed by placing the isotope source inside the engine with the film placed on the outside. The equipment does have inherent hazards and great care must be taken with its use. Only fully trained and licensed personnel should work with this equipment. Table 2 provides a list of the various available isotopes with their energies and applications.

TABLE 2 - RADIOISOTOPE SOURCES

Radioactive Element	Half-Life	Energy (MeV)	Applications
Thulium 170	127 days	0.084 and 0.54	Light alloys- 0.50 inch steel
Iridium 192	70 days	0.137 and 0.651	2.50 inch steel
Cesium 137	33 yrs	0.66	3.50 inch steel
Cobalt 60	5.3 yrs.	1.77 and 1.33	9 inch steel

Indications. The most common method of measuring x-ray or gamma ray transmission is with film. The film contains a silver emulsion which is sensitive to radiation. After exposure and development, the film will become proportionally darker depending on the amount of radiation which reached the film. Areas that are thinner or lower density will allow more radiation to pass through the part. The greater the radiation transmitted through the part, the darker the film will be (see figure 16).

Electronic devices may also be used to measure transmitted radiation. After passing through the test part, the radiation impinges upon a screen that emits light. This light is viewed by a camera which converts the images to electronic signals and transmits them to a CRT. With these devices, real-time viewing is possible. However, these systems are generally less sensitive and portable than film, harder to place in difficult to reach areas, and have considerable capital costs. Recent innovations, however, are making considerable progress

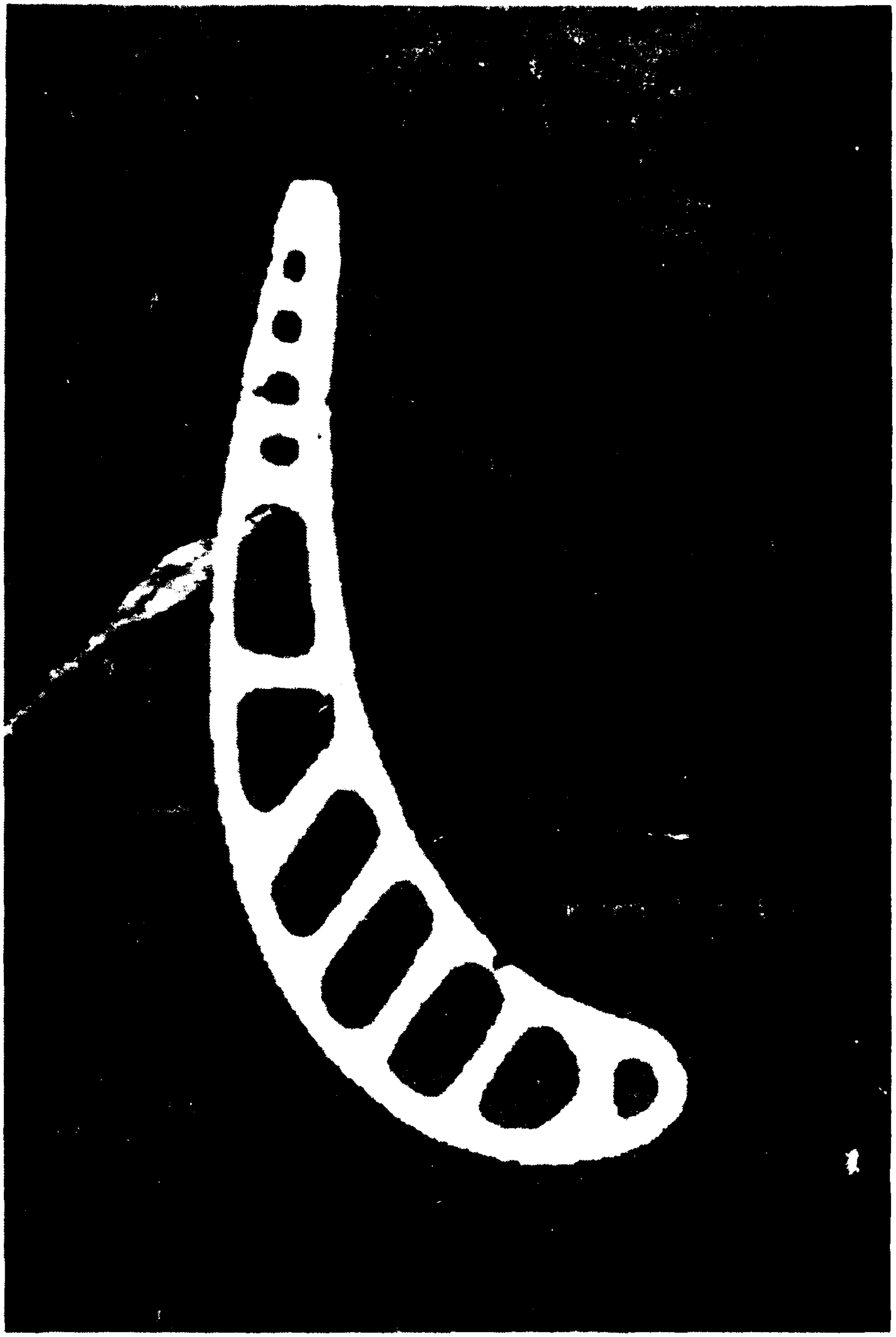


FIGURE 14. [illegible] MADE BY COMPUTED [illegible]

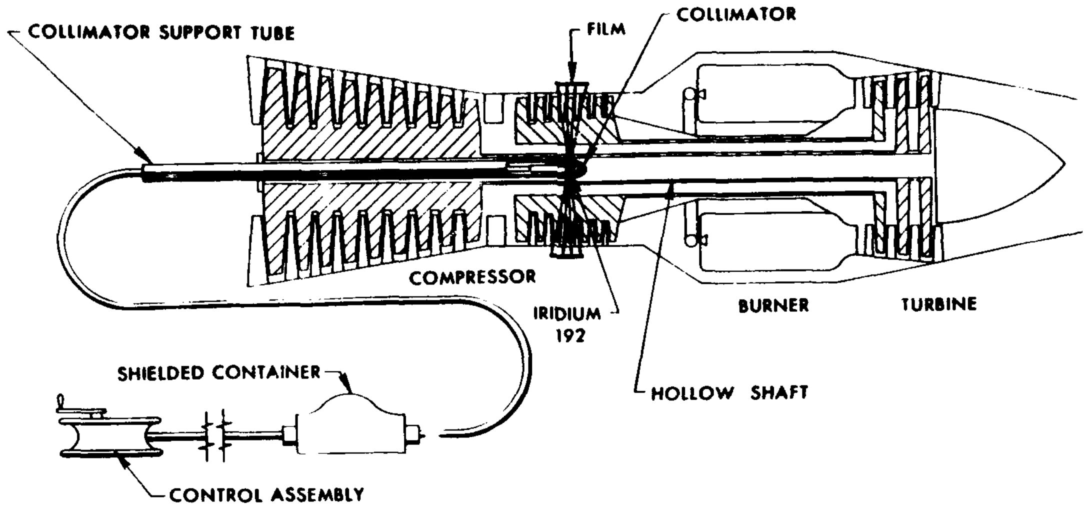


FIGURE 15. USING IRIDIUM 192 TO INSPECT AN ENGINE

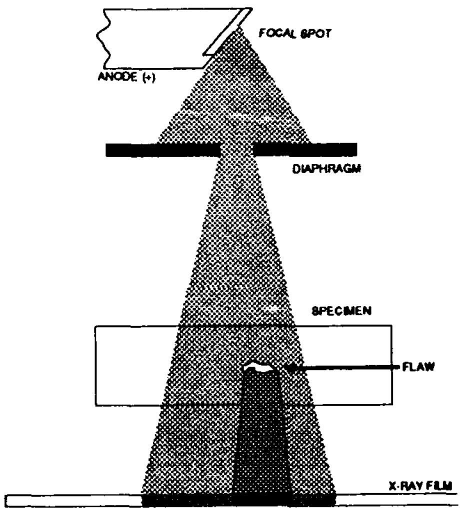


FIGURE 16. RADIOGRAPHIC EXPOSURE - MORE RADIATION PASSES THROUGH THE LOW DENSITY FLAW THAN THE SURROUNDING MATERIAL, CREATING AN AREA OF DARKER EXPOSURE ON THE FILM.

on all these fronts.

1. Radiographic Sensitivity (Image Quality) - Radiographic sensitivity is a function of two factors. The ability to see a density variation in the film, which is "radiographic contrast" and the ability to detect the image outline which is "radiographic definition". The factors affecting these parameters are discussed in detail below and summarized in table 3.

Radiographic contrast is the difference in darkness of two areas of a radiograph. If contrast is high, small defects or density changes will be noticeable. Contrast can be affected by either the subject or the film.

TABLE 3 - RADIOGRAPHIC IMAGE QUALITY

Radiographic Contrast		Radiographic Definition	
Subject Contrast	Film Contrast	Geometric Factors	Film Graininess Screen Mottle Factors
Affected by:	Affected by:	Affected by:	Affected by:
Absorption differences in specimen (thickness, composition, density	Type of film (characteristic curve)	Focal spot size	Type of film
Radiation quality	Degree of development (type of developer; time and temperature; degree of agitation	Target to film distance	Type of screen
Scattered radiation	Density	Part to film distance	Radiation quality
Scatter Reduced by:	Type of screens (florescent, lead or none)	Abruptness of thickness changes in specimen	Development
Masks and diaphragms		Relative motion of specimen	
Filters and lead screens			

Subject contrast is the difference in absorption of radiation by the part. The ratio of the absorbed radiation to the transmitted radiation is a function of the penetrating power of the radiation. High penetrating power will result in more transmitted radiation and the subject contrast will be low. Low subject contrast means lower sensitivity to small discontinuities. Using lower power will result in higher subject contrast. However, lower power requires longer exposure times to obtain the adequate film density. Too low an energy level will not penetrate the part at all.

Film contrast is the reaction of the film to the radiation and can enhance or diminish subject contrast. Film contrast is a function of the chemical composition of the film and the processing. The relation between the exposure applied to a film and the resulting density is called the characteristic curve, (see figure 17). Film contrast refers to the steepness of the characteristic curve of the film. At densities below 1.0 the film has a relatively flat curve and shows little contrast for large differences in radiation. This negates much of the subject contrast generated. At density levels of 2.0 and above, the film curve is steep, providing a large contrast difference for a small difference in radiation. This will enhance the subject contrast and create more radiographic contrast. Using the characteristic curve, an exposure level can be selected to result in the greatest contrast.

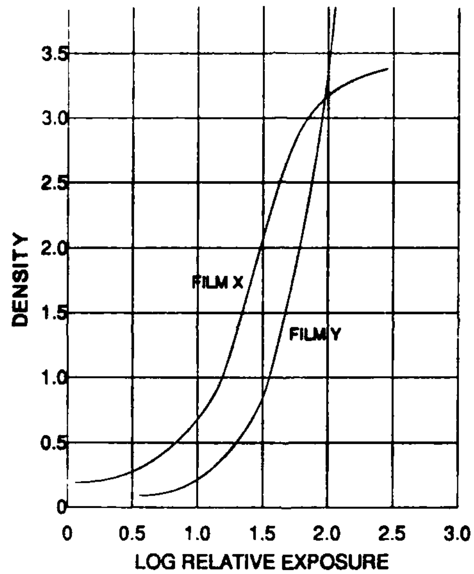


FIGURE 17. TYPICAL CHARACTERISTIC CURVES FOR TWO DIFFERENT FILMS

2. Radiographic Definition - This term is defined as the ability to resolve the defect image on the radiograph. It is also affected by the geometric factors used during the exposure. A combination of the geometric parameters of the exposure, including size of the radiation source (focal spot size), distance from the target/source to the film (TTF) and distance from the part to the film (PTF) can create geometric unsharpness. As the geometric unsharpness increases, the ability to see small defects decreases (see figure 18 and figure 19).

Film characteristics can also affect image sharpness. Fast films, those films that darken with less radiation, have large grains in their emulsion that cause a loss of definition. To achieve sharper images, slower, fine-grained films are required. Use of fluorescent screens to speed up exposures also contributes to image unsharpness.

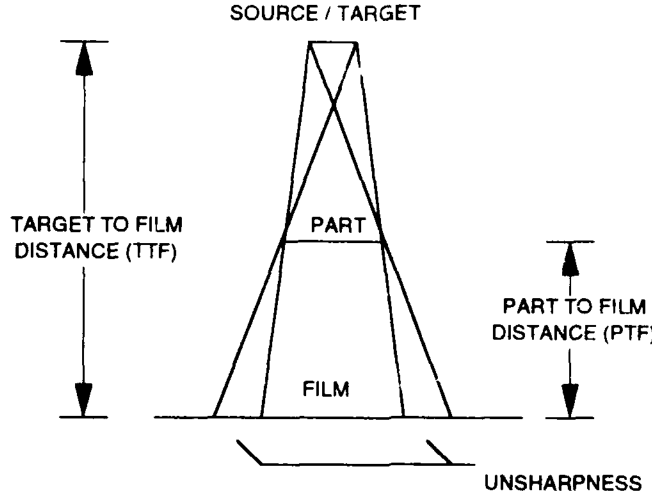


FIGURE 18. ILLUSTRATION OF GEOMETRIC FOCUS AND DIVERGING X-RAYS

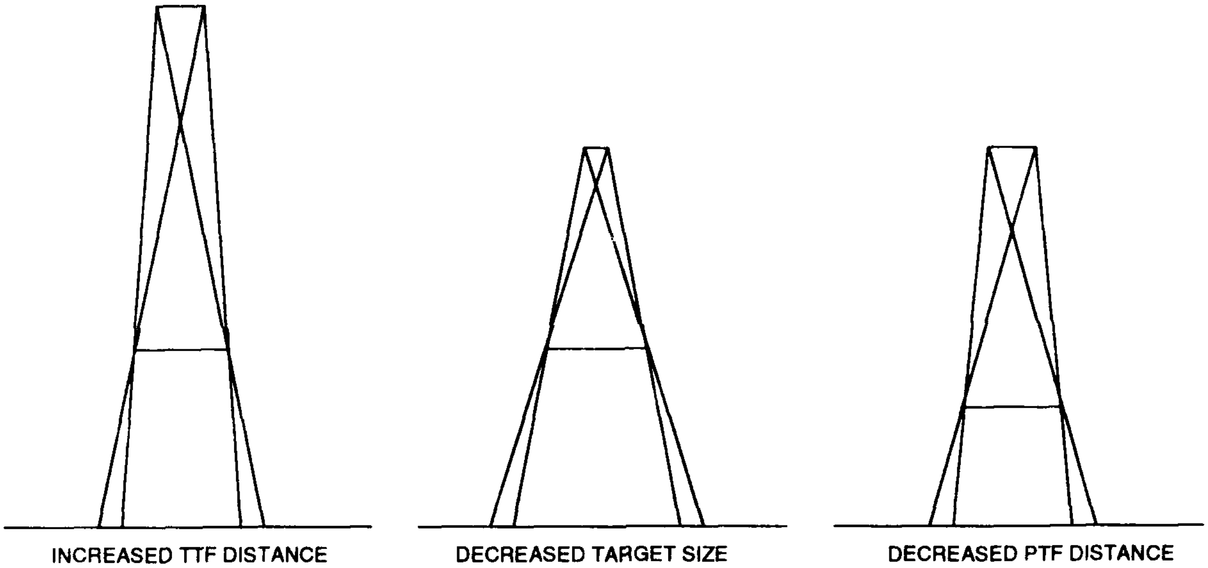


FIGURE 19. EXAMPLES OF GEOMETRIC EFFECTS - INCREASING THE TARGET TO FILM DISTANCE, DECREASING THE SOURCE APERTURE, OR DECREASING THE PART TO FILM DISTANCE WILL IMPROVE IMAGE SHARPNESS

Another factor affecting image definition is scattered radiation. Radiation striking objects creates secondary radiation called scatter. It can occur from walls or other objects in the exposure area (side scatter); from the part itself (internal scatter); or from objects behind the part (backscatter). This radiation affects the film in a manner not consistent with the part configuration and tends to blur the image and cause loss of definition.

3. Image Quality Indicators - Image Quality Indicators are used to measure the quality of the exposure and to assure that proper sensitivity has been achieved. They measure the definition of the radiograph. The most commonly used indicator in the United States is

the penetrameter. There are several minor variations of the penetrameter. Requirements for penetrameters are given in Mil-Std-453, ASTM E 142-68, and in the ASME boiler code.

The thickness of the penetrameter is usually 1 percent or 2 percent of the part thickness. They contain holes that are 1, 2, and 4 times the penetrameter thickness. By selecting the proper thickness penetrameter and assuring that the proper size hole is visible on the radiograph, one can verify that a given radiographic sensitivity has been achieved. For example, if a hole of diameter 2t (diameter equals twice the thickness) can be detected in a 2 percent thick penetrameter, the result is a 2-2t sensitivity or a 2 percent radiographic sensitivity. Required sensitivity is normally specified in an inspection requirement.

4. Screens - Fluorescent and lead screens are used to affect the exposure characteristics in radiography. Fluorescent screens emit light when exposed to radiation. They are used to shorten the film exposure time. In medical applications they are very important because they reduce the amount of radiation exposure by as much as a factor of sixty. However, they also add significantly to image unsharpness. Their application is prohibited when image quality is of primary concern. Lead screens can enhance exposure in two different ways. Since lead emits electrons when exposed to radiation, exposure times can be shortened. Lead screens also aid in eliminating scattered radiation by blocking the low energy scattered radiation which degrades image quality. They are used extensively on the backside of the film to eliminate backscatter. At penetrating powers above 150 kV they are used on the front side to eliminate internal scatter and reduce exposure.

5. Developing Film - Once the latent image has been generated on the film by exposure to radiation, the sensitized silver grains must be developed into a permanent image. The silver bromide grains are converted to metallic silver which produces the black image on the film. Developing times and temperatures are critical and image quality can be lost with improper controls. Exposure and film developing parameters must be coordinated to achieve the proper film density and sensitivity. Developing can be done manually, but most facilities use automatic processors which control the various cycle times and provide consistent developing.

6. Reading Film - Once a quality image is obtained, it must be read and interpreted. It is only with training and experience that proper interpretation of images can be achieved. Even with training, if proper equipment and facilities are not used, discontinuities can be missed.

Film is placed on a viewer for interpretation. The viewer must provide sufficient light intensity to penetrate the density of the image on the film. Background lighting should be subdued to eliminate reflections and to enhance film viewing. If small defects are to be detected, magnification may be used up to 10x. When the film contains large variations in density or the film does not cover the viewer, masking should be used to eliminate the excess light.

Part Preparation/Safety. Since, x-rays and gamma rays are excessively harmful to living tissue, extensive care must be used during application. Only properly trained personnel should perform this inspection. X-rays and gamma rays cannot be seen, felt, or detected without special equipment. Tissue damage can occur without any physical awareness of the radiation. Protection from radiation can be obtained with barriers of high density materials such as lead or concrete and surveys must be made of radiation facilities to assure proper protection is provided. Protection may also be provided by maintaining a buffer zone around the radiation source. The amount of radiation decreases proportionally to the square of the distance from the source. Areas utilizing radiation sources must be properly marked. Each state may have their own regulatory controls in addition to federal regulations. Regulations concerning the use of radioisotope sources are usually very strict.

Radiation survey meters are commonly used to monitor radiation and are especially important when using radioisotopes. Isotopes cannot be turned off. They are controlled by containment in high density containers. Before removal of the isotopes from their containers a sufficient area must be roped off to assure personnel exposures are below specified limits. When using isotopes, personal monitoring devices are normally worn. These are usually film badges that record the amount of radiation exposure that an individual has received. Measurement is made by developing the film and measuring its density. Instant reading dosimeters may also be used. They measure the ionizing effect of the radiation in a chamber by monitoring the loss of a static charge in that chamber. If the radiation outside an x-ray room is maintained below a given level, these devices may not be required for those areas. Periodic surveys must be made to assure this condition is maintained.

DEFECTS SOUGHT. Radiography is used on individual parts when looking for internal defects. It is not the preferred method for the inspection of surfaces which are accessible to other methods. Since radiography is expensive and susceptible to orientation problems with defects such as cracks, it is used where other, less expensive methods are not appropriate. It will only detect defects that produce a sufficient density change to affect the transmission of the radiation

through the part. This method is also used to detect water and corrosion in adhesive bonded honeycomb structures. Material thinning is detected using radiography by observing film density variations within the part.

METHOD CHARACTERISTICS.

Minimum Detectable Flaw Size. Variations in thickness down to approximately two percent of the total part thickness can be detected. For example, in a 0.100 inch thick aluminum sheet, a crack 0.002 inches deep could be found.

Advantages. The advantages of radiography include the detection of both surface and subsurface flaws and the ability to use it on all materials. It is also a very useful method in detecting different types of flaws such as corrosion, voids, and variations in density and thickness. All of the test results can be recorded permanently on film.

Disadvantages. The disadvantages of radiography are that operators require training as interpretation is sometimes difficult, orientation of the equipment and flaw is critical, and the equipment is relatively high in cost. Also, there is no indication of flaw depth unless multiple exposures are made, a radiation hazard exists, and film development time is required.

Probability of Detection/Probability of False Alarm. Radiographic inspection is generally less sensitive than other NDI methods for tight defects. It is especially poor at detecting fatigue cracks. The radiation beam must be nearly parallel to the depth of the crack for an indication to be detectable. However, it is still reliable enough to warrant extensive use in many areas.

Inspection Rate. Since it is necessary to develop the film after exposure, radiography is not a real-time inspection method in most applications. As mentioned above, CRTs are sometimes used to view the transmitted radiation. This method considerably speeds up the inspection at the expense of sensitivity.

Training. Training is necessary prior to performing a radiographic inspection. X-rays and gamma rays are detrimental to living tissue, therefore, extreme caution must be used during application. Proper training is also necessary to develop and interpret the radiographs. Film developing times and temperatures are critical and image quality can be lost with improper controls. Exposure and film developing parameters must be followed to achieve

proper film density and sensitivity. It is only with training and experience that proper interpretation of radiographic images can be achieved.

Portability. Typical x-ray systems have limited portability. However, gamma ray sources are quite small and portable with the ability to access many places that could not ordinarily be inspected by x-ray tubes.

TYPICAL EQUIPMENT USED TO INSPECT AIRCRAFT. Radiographic inspection of airplanes is accomplished either with x-ray or gamma ray procedures. X-ray inspection procedures are usually used for wing and fuselage structure. Gamma ray procedures are generally limited to engine inspection. X-ray inspection provides greater sensitivity and resolution than gamma ray inspection. The small radioactive source of gamma rays can be inserted into engines to accomplish inspections beyond the capability of larger x-ray tubes.

X-ray inspection of airplane structures is limited by the size and weight of the x-ray tube. In general, x-ray tubes up to a rating of 200 kV are considered portable and can be used in or on an airplane. X-ray tubes over 200 kV are generally used in permanent installations (shielded vaults) with hoisting equipment.

The following are some of the major manufacturers of portable x-ray tubes used by the commercial airlines to inspect aircraft structure:

Andrex Radiation Products
Balteau
Norelco
Philips Electronic Instruments
Sperry/Staveley NDT Technologies, Inc.
Seifert X-Ray Corp.

The primary radioactive isotope used in airplane inspection is Iridium. Two manufacturers of isotope inspection equipment used by the commercial airlines are:

Gamma Industries
Tech Ops, Inc.

The following is a partial listing of radiographic film makers and developers:

Agfa Matrix Corp.
DuPont NDT Systems
Eastman Kodak
Micro/Radiographs
X-Ray Products Corp.

The following are manufacturers of real-time radiograhic equipment:

Accu-Test, Inc.
BIR, Inc.
Brimrose Corp.
DTG Inc.
Digiray Corp.
Philips Industrial

ULTRASONIC.

DESCRIPTION OF METHOD.

General. Ultrasonic inspection utilizes high-frequency sound waves as a means of detecting discontinuities in parts. Sound waves are vibrations which cause an alteration in pressure or particle position. The waves travel through materials and are reflected from interfaces. The reflected beam is displayed and analyzed to determine the condition of the part. Sonic frequency, the number of cycles occurring in a unit time, is usually measured in cycles per second (cps) or Hertz (Hz). The average person can perceive sound in the range from 20-20,000 Hz, with the average male speech being approximately 128 Hz and a bat cry occurring at roughly 48,000 Hz. Ultrasonic test equipment usually operates in the range of 200,000-25,000,000 Hz (200 kHz to 25 MHz) with most inspections being performed at 5 to 10 MHz. The speed with which the sound waves travel through a material is dependent on the composition and density of the material. The speed of sound in aluminum is approximately 250,000 inches per second and 230,000 inches per second in steel. At this rate, the time it takes for a pulse to travel from the front surface to the rear surface and back to the front of 0.1 inch thick aluminum sheet is about one-millionth of a second. Sound, in the ultrasonic frequencies, does not travel far through air.

The characteristics of sonic or ultrasonic waves can be visualized by analogy with the behavior of waves in a body of water (see figure 20).

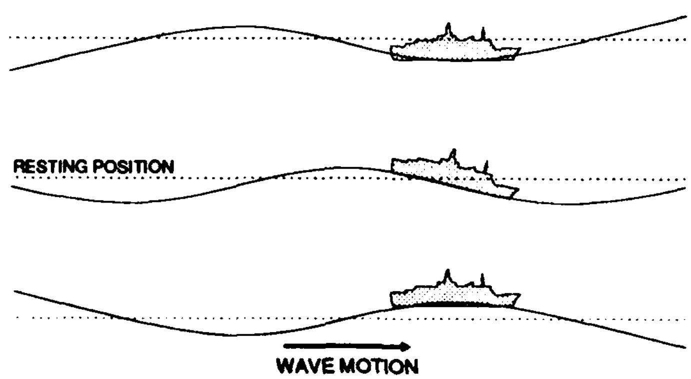


FIGURE 20. EXAMPLE OF ORDINARY WAVE MOTION

It may appear that the travel of the alternate crests and troughs is the actual movement of water particles. However, the water particles are not being horizontally translated. This is proven by the observation that an object on the surface does not move along with the waves, but only bobs up and down. The waves travel only in the sense

that the crests and troughs (which are comparable to the compressions and dilations of sonic waves) and the energy associated with the waves propagate through the water. The water particles remain in place and oscillate up and down from their resting positions. This behavior is similar for waves in any elastic medium.

Ultrasonic testing is accomplished by sending an electrical pulse to a transducer. This pulse causes the transducer to send a pulse of high frequency sound into the part. This pulse travels through the material until it reflects from a back surface or discontinuity. The reflected pulse is received by the transducer and converted back into an electrical signal. This signal is then transmitted to an oscilloscope for display (see figure 21). By examining the variations of a given response pattern, discontinuities are identified.

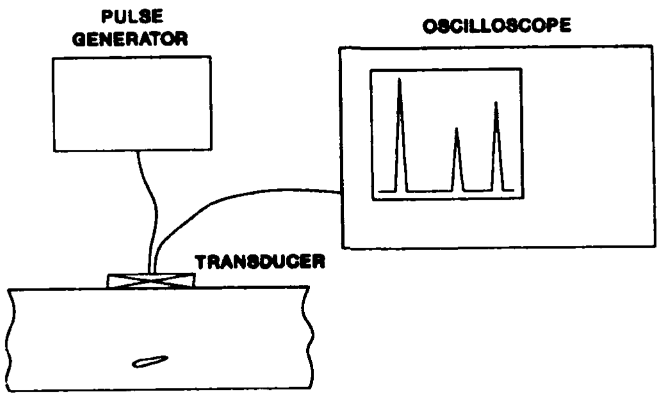


FIGURE 21. TYPICAL ULTRASONIC SYSTEM CONSISTING OF A PULSE GENERATOR, TRANSDUCER, AND OSCILLOSCOPE

Ultrasonic inspections can be performed with aircraft on the ramp or at the maintenance line, without requiring total disassembly. Some of the more common inspections are for large subsurface cracks in heavy section forgings, inspections of lugs for cracks initiating at connecting pin holes, and for inspection of installed bolts for large cracks. Detailed discussions of some ultrasonic inspection procedures are given in appendix B.

The following paragraphs describe the characteristics of ultrasonic testing, including the generation of waves, mode types, and sensitivity:

1. Wave Generation - Sound is transmitted into the test item by means of a transducer. Three materials which are commonly used in the manufacture of ultrasonic transducers are barium titanate, lithium sulfate, and polarized crystalline ceramics. These materials all use

a characteristic known as the piezoelectric effect. The piezoelectric effect causes crystals to expand and contract when subjected to an alternating electrical charge (see figure 22). Conversely, when these materials are subjected to alternating compression and tension loads, they develop alternating electrical charges on their faces.

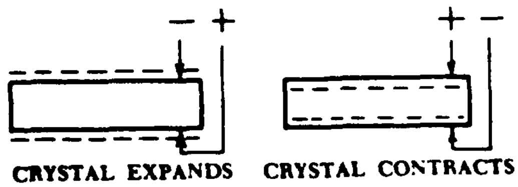


FIGURE 22. GENERATION OF ULTRASONIC WAVES

In order for a crystal to utilize its piezoelectric characteristics, it is placed in a circuit like a capacitor. That is, both faces are coated with a conducting material with no contact between the faces. Coatings may be of any conducting material such as aluminum, silver, gold, or chromium.

2. Wave Propagation - Ultrasonic waves can be propagated to some extent in any elastic material. The waves travel through the material causing the material to vibrate. An isolated group of these waves is called a wave train or pulse. A pulse may have one of several different forms depending upon the individual wave amplitude, and the way the waves build up and decay. The most widely used modes of vibration are longitudinal, shear, and surface waves. The mode is often determined by the angle at which the ultrasonic beam enters the material. This angle, called the angle of incidence, will be discussed following the sections on wave types.

Longitudinal waves, also called compression waves, are the type of ultrasonic waves most widely used in the inspection of materials (see figure 23). They occur when the beam enters the surface at an angle near 90 degrees. These waves travel through materials as a series of alternate compressions and dilations in which the vibrations of the particles are parallel to the direction of the wave travel. This wave is easily generated, easily detected, and has a high velocity of travel in most media. Longitudinal waves are used for the detection and location of defects that present a reasonably large frontal area parallel to the surface from which the test is being made, such as for corrosion loss and delaminations. They are not very effective,

however, for the detection of cracks which are perpendicular to the surface.

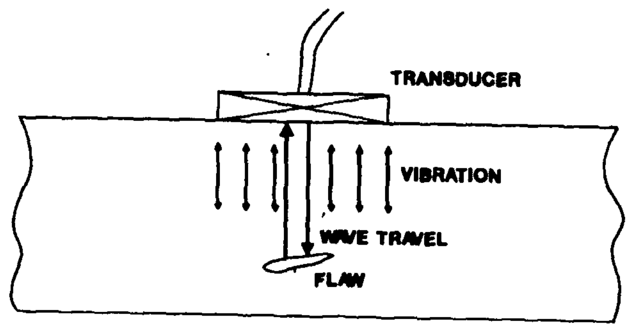


FIGURE 23. ILLUSTRATION OF PARTICLE MOTION IN A LONGITUDINAL WAVE

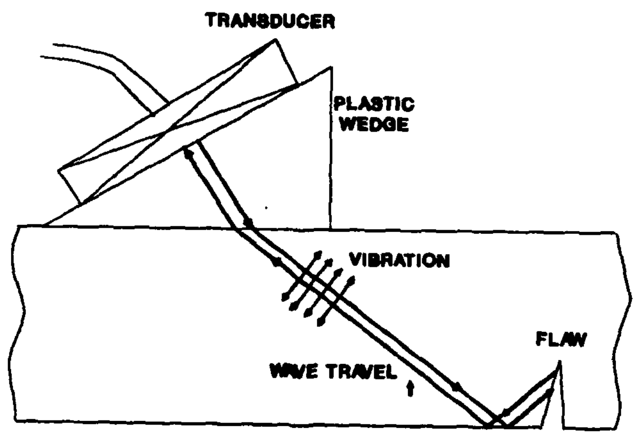


FIGURE 24. ILLUSTRATION SHOWING THAT PARTICLE MOTION IS PERPENDICULAR TO WAVE MOTION

Shear waves (transverse waves) are also used extensively in ultrasonic inspection and are generated when the beam enters the surface at moderate angles. As figure 24 shows, shear wave motion is similar to the vibrations of a rope that is being shaken rhythmically; particle vibration is perpendicular to the direction of propagation. Unlike longitudinal waves, shear waves do not travel far in liquids. Shear waves have a velocity that is about 50 percent of longitudinal waves in the same material. They also have a shorter wavelength than longitudinal waves, which makes them more sensitive to small

inclusions. However, this also makes them more easily scattered and reduces penetration. They are superior for locating fatigue cracks because the beam can travel nearly perpendicular to the flaws.

Surface waves (Rayleigh waves) occur when the beam enters the material at a shallow angle (see figure 25). They travel with little attenuation in the direction of propagation, but their energy decreases rapidly as the wave penetrates below the surface. The particle vibration follows an elliptical orbit consisting of both longitudinal and shear wave motion. These waves have a velocity of approximately 90 percent of the transverse wave velocity in the same material. They are affected by variations in hardness, plated coatings, shot peening, and surface cracks, and are easily dampened by dirt or grease on the specimen. The waves will travel around curves and surface contours, but will reflect from sharp corners associated with flaws or edges of plates.

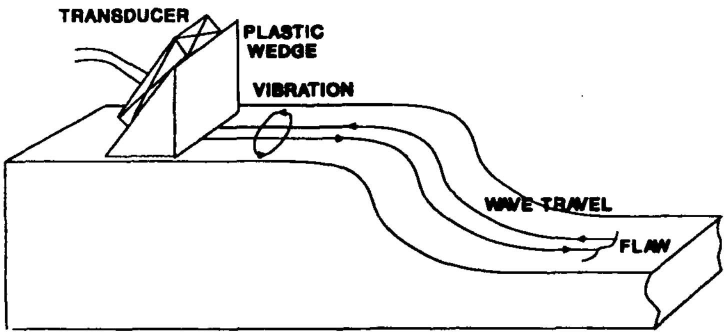


FIGURE 25. SURFACE WAVE PARTICLE MOTION IS ORBITAL, CONSISTING OF BOTH PARALLEL AND PERPENDICULAR COMPONENTS

Most shear wave and surface wave inspections performed on airplanes are accomplished using transducer assemblies that have a plastic (generally lucite) wedge attached to the face of the transducer. The plastic wedge is cut to the shape and angle needed to generate a specific ultrasonic mode and angle in the part being inspected. For example, the test might require a shear wave inspection at 45 degrees in aluminum or a longitudinal beam at 10 degrees in a steel surface with a radius of curvature of 4 inches. These angle beam transducers are available commercially, however, some airlines prefer to fabricate their own.

Lamb waves, also known as plate waves and guided waves, occur when ultrasonic vibrations are introduced at an angle into a relatively thin sheet (see figure 26). A Lamb wave consists of a complex vibration that occurs throughout the thickness of the material,

somewhat like the motion of surface waves. The propagation

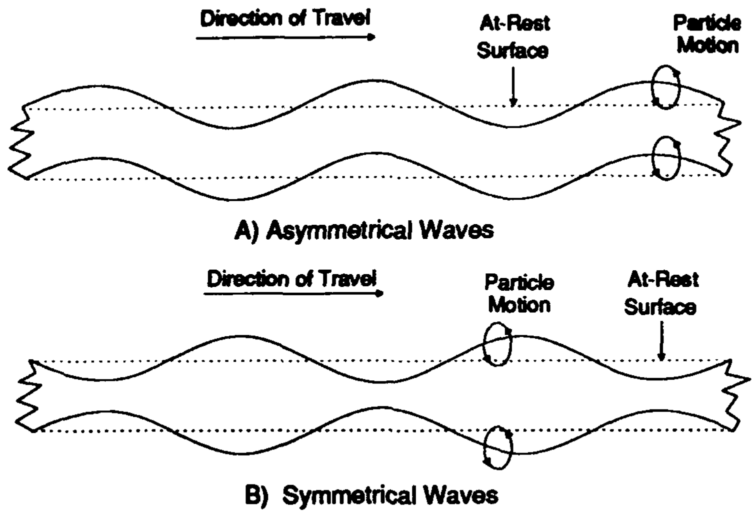


FIGURE 26. LAMB WAVES OCCUR ONLY IN THIN SHEETS OF MATERIAL IN EITHER ASYMMETRICAL OR SYMMETRICAL MODES

characteristics of Lamb waves depend on the density, elastic properties, and structure of the material as well as the thickness of the test piece and the frequency of the vibrations. Their behavior is analogous to that of electromagnetic waves traveling through waveguides. There are two basic forms of Lamb waves; symmetrical (dilatational), and asymmetrical (bending). Each form is further subdivided into several modes having different velocities that can be controlled by the angle at which the waves enter the test piece. Lamb waves can be used for detecting voids in laminated structures, such as sandwich panels.

There are few applications where Lamb waves are used for the inspection of airplanes other than their use for detecting voids in laminated structure as noted above. In this regard, there are some ultrasonic bond testers that generate Lamb waves for the inspection of thin, bonded or laminated structure.

As previously mentioned, the angle of incidence (figure 27, angle a_1) determines the mode with which the wave will travel through the part. If the angle from the normal is small (near perpendicular to the surface), sound waves propagating through the medium may undergo mode conversion at a boundary, resulting in the simultaneous propagation of longitudinal and transverse waves. If the angle is increased, the direction of the refracted longitudinal wave will approach the plane of the boundary ($B_1 \rightarrow 90°$). At some specific value of a_1, B_1 will exactly equal 90 degrees, above which the refracted longitudinal wave will no longer travel in the material, leaving only the refracted shear wave in the second medium. This value of a_1 is known as the

first critical angle. If a_1 is increased beyond the first critical angle, the direction of the refracted shear wave will approach the plane of the boundary ($B_t \rightarrow 90°$). At a second specific value of a_1, B_t will exactly equal 90 degrees, above which the refracted transverse wave will no longer propagate in the material. This second value of a_1 is called the second critical angle. Above this angle only surface waves will propagate.

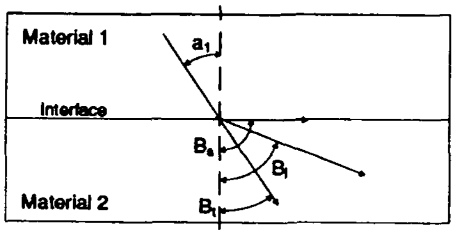


FIGURE 27. ANGLE OF INCIDENCE DETERMINES WHETHER A LONGITUDINAL, SHEAR, OR COMBINATION WAVE IS GENERATED IN THE MATERIAL

Critical angles are of special importance in ultrasonic inspection. Because longitudinal and shear waves propagate at different rates, confusing echo patterns may occur if both are present within the test part. The incidence angle is usually adjusted to eliminate one type of wave mode. Values of a_1 between the first and second critical angles are required for most angle-beam inspections. Surface wave inspection is accomplished by adjusting the angle of the transducer so that it is slightly greater than the second critical angle. Table 4 lists examples of critical angles for various metals.

TABLE 4 - CRITICAL ANGLES FOR IMMERSION AND CONTACT TESTING IN VARIOUS METALS

	First Critical Angle (Degrees)		Second Critical Angle (Degrees)	
Metals	Immersion	Contact	Immersion	Contact
Steel	14.5	26.5	27.5	55
Type 302 Stainless	15	28	29	59
Type 410 Stainless	11.5	21	30	63
Al 2117-T4	13.5	25	29	59.5

3. Sensitivity - Sensitivity, resolution, and noise discrimination are among the most important factors limiting the use of ultrasonics. Sensitivity is the ability to detect the small amount of energy reflected from a discontinuity. Resolution is the ability to separate and distinguish the indications from several defects lying close together. Noise discrimination is the capacity of the

instrument for differentiating between the signals from defects and unwanted noise of either electrical or acoustical nature. A small defect in a material with a very large grain structure would be very difficult to detect, since the flaw reflection would be hard to separate from the background noise. The above variables are all affected by frequency and pulse energy. For example, when frequency is increased, the wavelength of the pulses becomes shorter and the sensitivity of the instrument increases. However, with the increase in sensitivity, smaller inhomogeneities within the material will become detectable. This means that background noise will increase, thus hindering signal discrimination. Increasing pulse energy will also increase material noise and decrease resolution. Therefore, there is always a practical limit to frequency and pulse energy levels depending on the material. In a very fine grained material, frequency and energy can be increased until very small flaws are detectable. In a coarse grained material it will be impossible to detect a flaw of similar size.

Equipment. There are two basic methods of ultrasonic inspection, and they determine the equipment required. The first method is contact inspection and the second is immersion inspection. Contact equipment is small and portable, requiring only the instrument, transducer, couplant, and a reference standard. Most airframe components are inspected using contact type equipment. Contact transducers are divided into two types which produce the desired wave mode: the straight-beam technique for transmitting longitudinal waves, and the angle-beam technique for generating shear waves and surface waves.

The straight-beam technique is accomplished by projecting a sound beam perpendicularly to the surface of the test specimen to obtain pulse-echo reflections from back surface or from discontinuities which lie between the two surfaces. Figure 28 shows a typical contact pulse-echo setup.

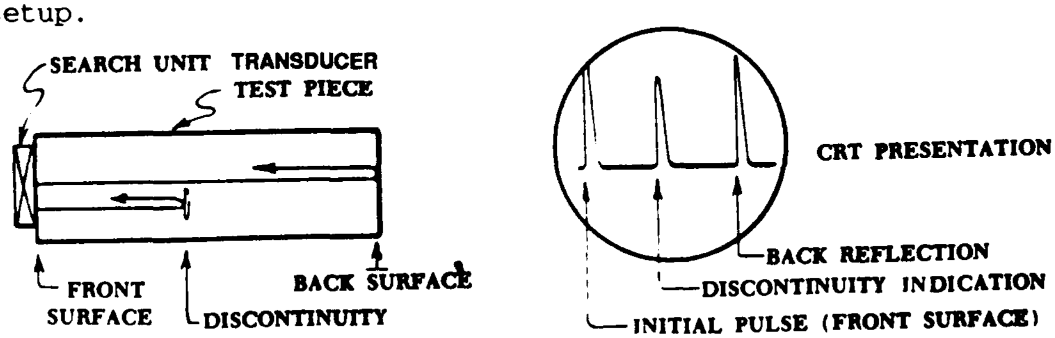


FIGURE 28. TYPICAL SETUP AND DISPLAY OF PULSE-ECHO TESTING

Angle-beam techniques are used to transmit sound waves into the test material at a predetermined angle to the test surface so that shear

waves are produced. These angle-beam transducers are especially good for inspecting piping and butt welds in flat plates (see figure 29).

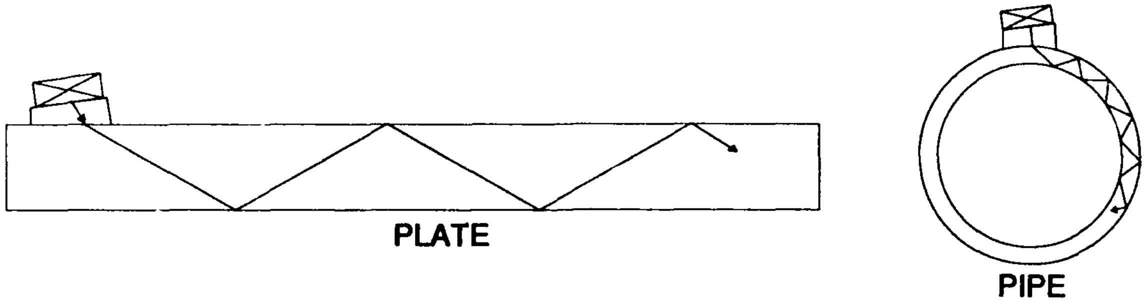
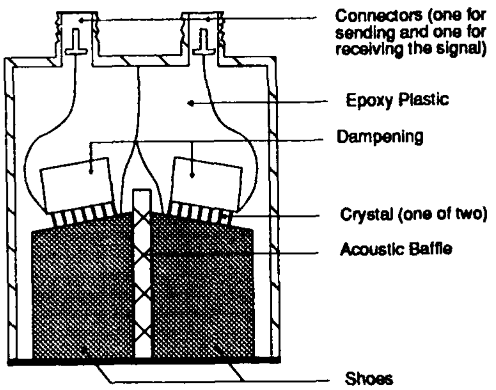


FIGURE 29. APPLICATIONS OF ANGLE BEAMS FOR ULTRASONIC INSPECTIONS

Both straight beam and angle beam equipment sometimes utilize dual transducer or "pitch-catch" arrangements. The double transducer unit is useful when the test surface is rough or when the specimen shape is irregular and the back surface is not parallel with the front surface. One transducer transmits and the other receives. Figure 30 shows two typical dual transducer arrangements. One for straight beam and one for angle beam.



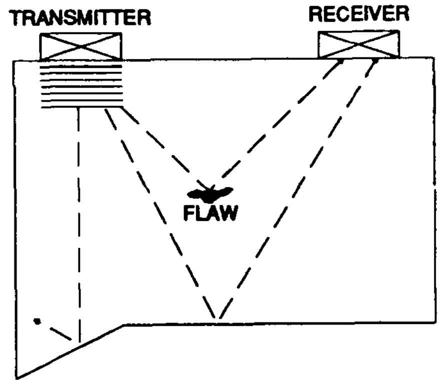


FIGURE 30. ILLUSTRATIONS USING SEPARATE TRANSDUCERS FOR SENDING AND RECEIVING, OR "PITCH-CATCH"

Immersion equipment transmits the sound into the specimen through a water path or column, (see figure 31). When both the search unit and the part are totally immersed it is known as immersed scanning. Immersion equipment is much heavier than contact equipment and therefore it is usually stationary. Engine components are often removed and inspected by immersion type equipment.
Bubbler or squirter (see figure 32) scanning projects the sound beam from an immersed search unit into the part through a column of water. A wheel scanning unit is a type of immersion scanner that incorporates some principles of contact testing. It consists of a transducer mounted on the axle of a wheel within a liquid filled rubber tire,

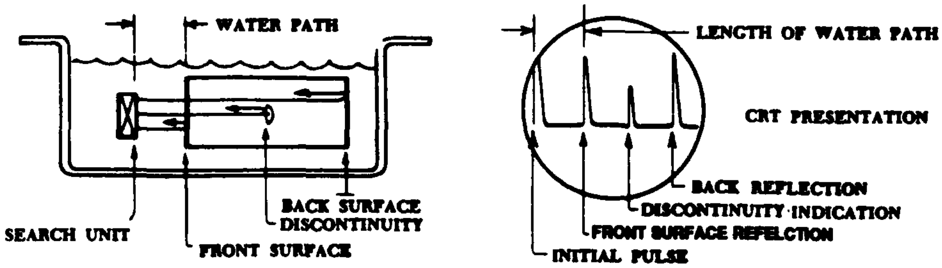


FIGURE 31. TYPICAL SETUP AND DISPLAY FOR ULTRASONIC IMMERSION TESTING

(see figure 33). The transducer is held in a fixed attitude relative to the test surface while the wheel rotates freely. The sound beam is transmitted through the liquid and the tire into the part.

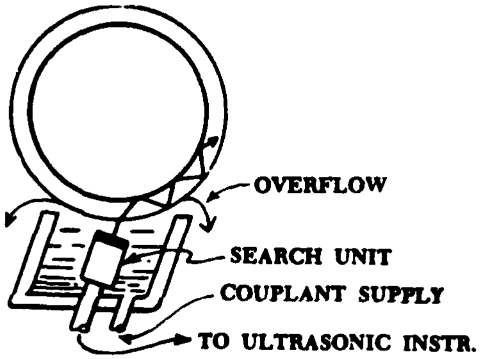


FIGURE 32. BUBBLER ANGLE-BEAM TESTING FOR PIPE INSPECTION

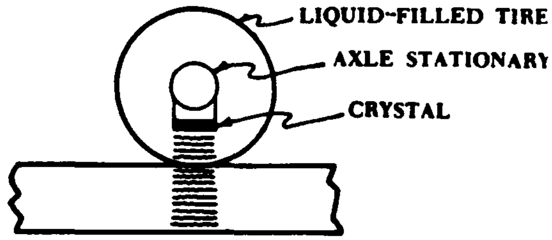


FIGURE 33. ILLUSTRATION OF A WHEEL TRANSDUCER

The basic components of an ultrasonic flaw detector consist of:

1. Power supply - to produce the various required voltages.

2. Rate generator or timer - to start and synchronize all other functions.

3. Pulser or pulse generator - the source of short high-energy bursts of electrical energy (triggered by the timer) which are applied to the transducer.

4. Transducer (crystal) - transmits a high-frequency sound wave into the test piece, receives the reflected echo, and converts it into an electrical pulse.

5. Amplifier or receiver - to amplify and properly prepare the echo signal for display.

6. Oscilloscope - which presents a graphic representation of the echo signals.

7. Couplant - usually water, oil, or grease is needed.

8. Plastic wedge - usually required to hold the transducer at the proper angle and position.

Indications. Ultrasonic echoes are often presented visually on oscilloscopes. Three different presentation formats may be used: the A-scan, B-scan, or C-scan.

1. A-scan - This format is the most common type of presentation used in commercial ultrasonic inspection and consists of a horizontal base line which indicates elapsed time between the pulse and the return. Reflections are shown as deflections from the base line. The horizontal position of the deflections indicate depth. The amplitude represents the intensities of the reflected beams that can be related to flaw size, sample attenuation, or other factors. The trace is set up to show a reflection from the top and bottom of the part and reflections due to flaws will appear between the two.

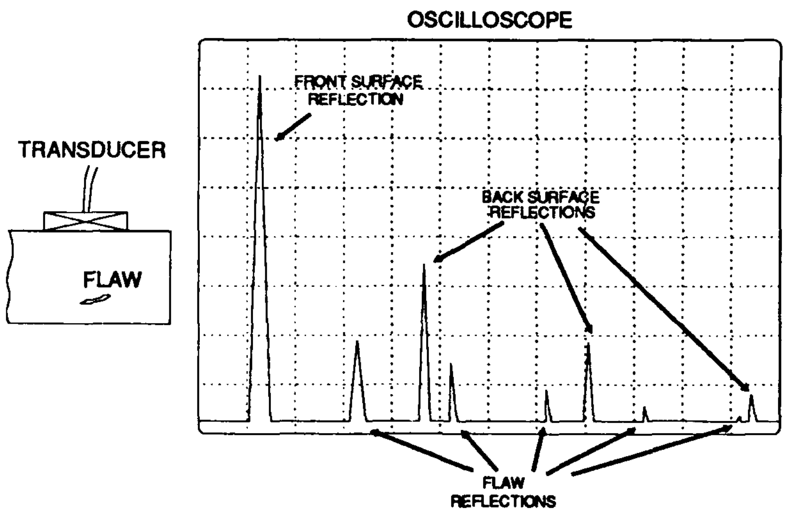


FIGURE 34. ILLUSTRATION OF A TYPICAL A-SCAN DISPLAY

An A-scan pulse, return and display works in the following manner (refer to figure 34). The pulse generator sends a signal to the transducer crystal. The crystal generates a sound pulse which is transmitted into the part. A portion of the pulse is immediately reflected at the transducer/material interface. The remaining energy then penetrates into the part. The primary pulse reflects from the back surface and returns to the transducer. If there is a flaw in the

material, it will be between the front and rear reflections. A secondary reflection is created by part of the primary pulse reflecting from the inside of the front surface. Another secondary pulse is created by the reflection of the back side of the flaw. All these secondary reflections will result in deflections from the baseline signal on the display. In time, the secondary reflections will decrease to an undetectable level. For most aircraft applications, all this happens in a fraction of a second.

2. B-scan - A B-scan utilizes the same signal as an A-scan, but then presents it along a line as the transducer is scanned along the part. The display results in a "cutaway" view of the part. The location and depth of the flaw can be determined, but in the case of small defects, only a rough estimation of flaw size can be obtained (see figure 35).

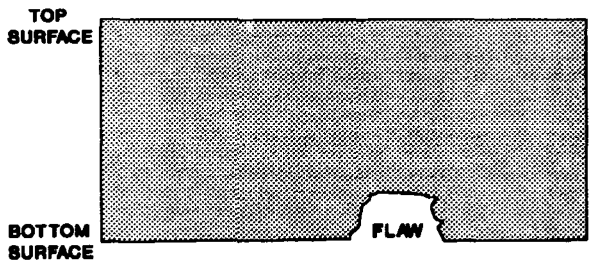


FIGURE 35. ILLUSTRATION OF A TYPICAL B-SCAN DISPLAY SHOWING CROSS-SECTIONAL VIEW

3. C-scan - The C-scan presentation involves scanning the transducer over an area (see figure 36). Results are displayed like a plan view looking down on the part under test. The display is similar to a radiograph of the part. A two dimensional scanner records the movement of the transducer and a scale image is created on a video monitor. Flaw depth cannot be determined from the C-scan.

<u>Part Preparation/Safety.</u> Ultrasonic inspection does not require part disassembly or removal. However, access to the desired area must be acquired. Consequently, some fairing or access panel removal and limited adjacent equipment disassembly may be required. Limited scale or corrosion removal may be required on steel forgings to provide a smooth surface. Heavy paint and dirt will absorb most of the sound energy and must sometimes be removed before inspection. The surface condition of the part must be inspected. A rough surface with numerous pits and bumps is difficult to inspect due to the unsteady pattern of the response.

In addition, some equipment preparation is needed. It is essential that the equipment be calibrated to a reference standard or test block

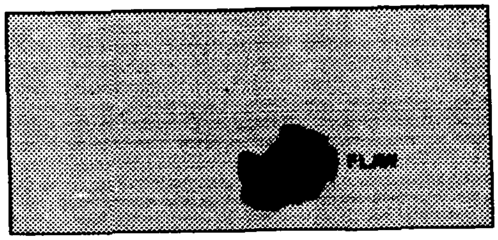


FIGURE 36. ILLUSTRATION OF A TYPICAL C-SCAN DISPLAY SHOWING TOP DOWN VIEW

that matches or simulates the part being inspected and which contains a known flaw. A mount to hold the transducer head in the proper relationship to the part must be obtained or fabricated. A couplant, as suggested by the individual inspection requirement, must be selected.

DEFECTS SOUGHT. Ultrasonics is a fast, reliable nondestructive testing method that will penetrate metals, liquids, and many other materials. Because ultrasonic techniques are basically mechanical phenomena, they are particularly adaptable to the determination of structural integrity of engineering materials. Materials include: metals, wrought metals, welds, brazed joints, adhesive bonded joints, non-metallic and in-service parts. Principle applications consist of:

Flaw detection. This method is able to detect cracks, laps, seams, laminations, inclusions, rolling cracks, and other defects in raw material or installed parts. Porosity, cupping, internal ruptures, and nonmetallic inclusions can also be detected. Weld defects, such as cracks, blow holes, insufficient penetration, lack of fusion, and other discontinuities can be found. Forgings, such as turbine shafts and rotors, can be inspected for defects.

Thickness measurement. Pulse-echo contact techniques can be used to make thickness measurements. The results of this test can be displayed on an oscilloscope or a meter. The same signals can also be used to activate an alarm when the test piece is out of tolerance. Pulse-echo testing is capable of measuring a wide variety of

thicknesses with the minimum thickness being determined by the frequency of the ultrasonic waves.

Determination of material degradation.

1. Corrosion Detection - Surface corrosion, exfoliation, stress corrosion cracking, general material thinning, pitting and intergranular corrosion can be detected by ultrasonic techniques. It is measured by using pulse-echo techniques to determine changes in the thickness of the part under test. This method may be difficult to use on aircraft structures because the area under test may include bonded regions, thus providing a signal whose origins cannot easily be determined. Despite this drawback, ultrasonic thickness measurements are frequently used to determine corrosion thinning and to monitor the rate at which it occurs.

2. Bond Quality - Delaminations and lack of bond in brazed joints and honeycomb materials can be inspected by ultrasonics. A majority of bond testing is performed by pulse-echo methods. A good bond will show three indications on an oscilloscope, the initial pulse, a small indication from the bond line, and the reflection from the opposite face. Areas where the bond line signal is minimum are assumed to have an acceptable bond. Where the bond line signal is larger, the bond is questionable and if there is no reflection from the opposite face, there is no bond present. Bonded aircraft structure, which is made up of thin skins, produce multiple back reflections on the oscilloscope. The method of reading these multiple reflections is called the "ringing technique." When a void is present, the reflection pattern changes and no ringing is observed. Testing of bonded aircraft structures is difficult because of so-called "kissing disbonds." These are areas of disbonds which are held tightly together by compression forces in the airframe. Ultrasonically, these bonds may be indistinguishable from acceptable bonds, however, their ability to carry a load is greatly reduced.

METHOD CHARACTERISTICS.

Minimum Detectable Flaw Size. Flaws as small as 0.050 inches diameter are detectable by both immersion and contact ultrasonic techniques, however, ultrasonic testing applications on airplanes are so varied that it is best to determine the detectable flaw size for each application.

Advantages. The advantages of using ultrasonic inspection techniques include its versatility in requiring access to only one surface of the specimen and the wide range of materials and thicknesses that can be inspected, rapid response of the system, the

capability of automating the inspection application, accuracy in determining flaw position and size, high sensitivity permitting detection of minute defects, detection of both surface and subsurface flaws, permanent data storage, and minimal part preparation and special safety precautions.

Disadvantages. The disadvantages of the ultrasonic test method are that is requires a high degree of experience and skill required to set up and interpret the results, and both couplant and reference standards are required.

Probability of Detection/Probability of False Alarm. Detectability varies with material and flaw size and part geometry. To obtain accurate results, great care must be taken during test setup. Transducers must be matched to the material and type of wave desired. The wave type is determined by suspected crack orientation and depth. Frequency must be matched to flaw size, depth, and material structure. To reach a high level of confidence all of these factors should be considered.

Inspection Rate. Ultrasonic inspection yields immediate results which can be viewed on an oscilloscope or detected audibly.

Training. Simple ultrasonic testing, such as thickness measurement, can be accomplished without much training. However, searching for flaws in critical parts requires a high degree of experience and skill. Inspection setup and interpretation must be performed by qualified personnel who are acquainted with the equipment and procedures.

Portability. Contact type ultrasonic equipment is highly portable. Systems are hand-held and can weigh from 2 to 20 lbs.

TYPICAL EQUIPMENT USED TO INSPECT AIRCRAFT.

Flaw Detection Instruments. The following are portable battery powered pulse-echo instruments that use a single transducer to both generate and receive the return echo. The instruments have an oscilloscope display, unless otherwise noted.

Model	Manufacturer
Pulsar 5000 series	Dupont NDT Systems, Inc.
USIP-11 and -12 USL-32, -38, -42, -48 USD-10, Digital Scope Display	Krautkramer-Branson, Inc.

Echograph 1013, FX-5, FX-7	Karl Deutsch/Magnaflux
Sonic -132 and 136	Staveley Instruments, Inc.

Bond Inspection Instruments. The following bond inspection instruments are capable of detecting disbonds or voids in a variety of materials. They are not capable of identifying variations in bond strength:

Model	Manufacturer
ABE(Advanced Bond Evaluator) LCD Readout No Couplant Required Battery Powered	Uniwest
Fokker Bond Tester 70 Meter and Scope Readout Requires Liquid Couplant Requires Line Power	Fokker/Halo Instruments
Sondicator S-2B Meter Readout (Out of Production) No Couplant Required Battery Powered	Automation Industries
S-3 Audible Bond Tester Earphone Readout No Couplant Required Battery Powered	Zetec, Inc.
S-5 Sondicator Bond Tester Meter Readout No Couplant Required Battery Powered	Zetec, Inc.
210 Bond Tester Meter Readout Requires Liquid Couplant Battery Powered	Dupont NDT Systems, Inc.

Thickness Gauges. The following ultrasonic instruments are designed for measuring thickness from one side of a part. An ultrasonic transducer is placed on the part with a liquid couplant. The instruments provide a digital reading of the thickness to an accuracy of $\pm$ 1 percent. Measurements can be taken in metals and

dense non-metals such as glass or plexiglass. The instruments are not recommended for measuring moderate to severe corrosion loss.

Model	Manufacturer
104 Digital Caliper CL 204 and CL 304 Thickness Gauges	Krautkramer-Branson, Inc.
Nova 201 and 800 Series Thickness Gauges	Dupont NDT Systems, Inc.

PENETRANT.

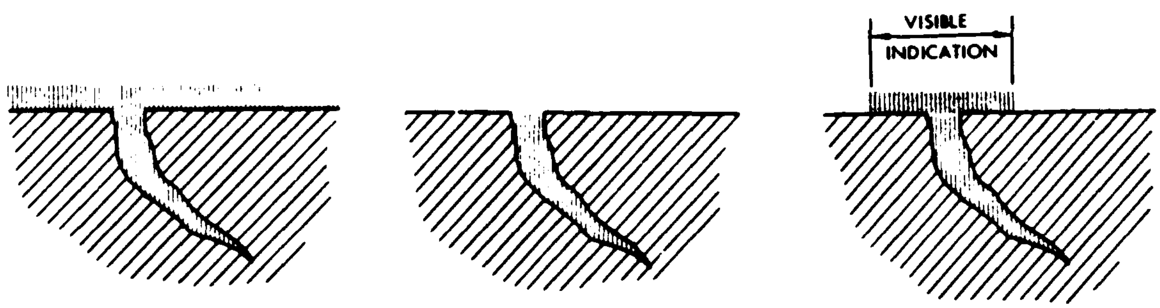
DESCRIPTION OF METHOD.

General. The penetrant method is used to nondestructively inspect solid, nonporous materials by revealing fine surface defects that are not readily visible to the unaided eye. There are several different types of penetrants, each requiring specific knowledge of their respective applications.

In general, the penetrant method involves applying a penetrating liquid to the surface of the part to be inspected. By capillary action, the penetrant is drawn into any tight, surface breaking defects (see figure 37). Excess liquid on the surface is then removed, leaving behind the penetrant which has entered into the defects. This penetrant is then drawn out from the defects toward the surface by a blotting agent called a developer. The surface of the part is then examined for the presence of the penetrant which typically contains either a visible or fluorescent dye to make it readily visible under the proper lighting conditions. The bleed-out or developing action provides an indication that is somewhat larger than the actual defect size, allowing it to be more readily detectable.

In order to perform accurate penetrant inspections, it is imperative to maintain strict adherence to all process specifications.

1. Penetrant Application - Penetrant may be applied by dipping, spraying, or brushing as long as complete coverage is achieved. Dipping provides positive coverage, but excess penetrant can be removed along with the part, causing usage rates to be higher than with spraying methods. Pressure spraying may use less penetrant, but



(A) LIQUID PENETRANT, APPLIED TO SURFACE, SEEPS INTO DEFECT

(B) PENETRANT REMOVED FROM SURFACE, BUT DEFECT REMAINS FULL

(C) DEVELOPER ACTS AS A BLOTTER TO DRAW PENETRANT OUT OF SURFACE DEFECT AND PRODUCE VISIBLE INDICATION

FIGURE 37. PENETRANT AND DEVELOPER ACTION

is operator dependent for uniform coverage unless an automated system is used. Care must be taken to ensure that all areas are covered. In electrostatic spraying systems, the penetrant is given an electrical charge and the part is grounded so that the penetrant is electrically drawn to the part. This decreases over-spray and reduces penetrant waste. Electrostatic spraying tends to draw the penetrant to the backside of parts, ensuring coverage. It does not, however, work well on deep cavities because the penetrant is drawn to the edge of the opening, preventing penetration into the cavity. Proper ventilation must be provided whenever penetrants are sprayed. Brushing is usually performed for localized application only, and is not a practical application method for large areas or for a large number of parts. The penetrant typically should remain on the part from 10 minutes to 2 hours to allow capillary action to be effective.

2. Penetrant Removal - Removal of excess penetrant can be accomplished with either an emulsifier, solvent, or water depending upon the type of penetrant used.

Emulsifiers aid in the removal of certain types of penetrants. They are normally applied by dipping, but may be applied by pouring or spraying. Timers are used to ensure that over-emulsification does not occur. Lipophilic emulsifiers are oil based and may be stored in steel tanks. Hydrophilic emulsifiers are water based and utilize rust preventatives to enhance their effectiveness.

Solvent removable penetrants are used in portable systems in places where access to water is limited. Application does require additional time and caution compared to water-washable penetrants and for this reason, it is typically used only for spot inspections or where other methods are not feasible.

Several types of penetrants can be removed by washing with water, sometimes in a two-step process. In hydrophilic systems, a prewash cycle using a water spray is necessary for the removal of the bulk of the excess penetrant. The resultant effluent is a mixture of oily penetrant and water that requires treatment to comply with environmental protection regulations. In many systems, charcoal filters and/or coalescors are used to separate the oil from the water and the water is then reused in the wash station.

The final wash station may consist of an agitated dip or a spray. Care must be taken at this station to prevent over-wash. Ultraviolet light may be used to monitor the wash cycle to assure adequate removal of fluorescent penetrant. The effluent from this station contains soaps as well as penetrant and water, and cannot be readily separated at the wash station for reuse. Fresh water is added to keep the

contamination at an acceptable level. Reused water is sometimes used as a preliminary rinse with the final rinse utilizing fresh water.

3. Drying - Parts must be air or furnace dried before applying dry developers or after applying wet developers. Care must be taken to prevent excessive drying since the penetrant in the defects can lose its carrier fluids and not respond later during the developing process. Both time and temperature must be carefully controlled throughout the drying process.

4. Developing - Wet developers are normally applied by dipping or spraying prior to drying. If suspended wet developers are used, agitation must be provided to ensure that the developer does not settle to the bottom of the tank. Tanks must be periodically checked for penetrant contamination from previously processed parts. Dry developers are applied by cloud chambers or by blowing the powder onto the part. Reused powder must be checked for penetrant contamination. It is important that the system be kept dry since the presence of moisture will tend to cake the powder. Nonaqueous developers are applied by spraying. Proper ventilation must be provided due to the volatile nature of the carrier fluid. Sufficient time should elapse after application of the developer before inspection is begun. Normal dwell time for the developer ranges from 10 to 30 minutes. A longer dwell time can cause excessive diffusion of the developer and blur defect indications.

5. Specifications - In an attempt to unify penetrant inspection requirements, the airlines, aircraft manufacturers, penetrant manufacturers, and the U.S. Air Force met under the auspices of the ATA and SAE to generate a consensus document for controlling penetrant inspection at airline overhaul facilities. The resultant document is AMS 2647 Fluorescent Penetrant Inspection, Aircraft and Engine Component Maintenance, which was published April 1, 1985. This document contains the agreed upon controls required for the penetrant inspection process.

The following is a partial list of various process parameters that must be controlled within specified limits. Generally accepted limits are listed below:

Penetrant temperature	60 - 100 degrees F
Penetrant dwell time	10 min - 2 hrs
Water pressure	40 psi max
Water temperature	50 - 85 degrees F
Drying temperature	160 degrees F max
Developing time	10 min minimum
Light intensity (visible penetrants)	75 - 125 ft-candles

UV intensity (fluorescent penetrants) 800 microwatts/sqcm @5 in min
Background light (dark booth) 2 ft-candles maximum

Equipment.

1. Application Equipment - The equipment used in penetrant inspections can range from simple aerosol cans used in portable systems to fully automated systems with computer control of each process station. Stations include penetrant application, washing, drying, developer application, and inspection (see figure 38).

Self-contained inspection kits are used for inspection in the field where shop facilities are not available. They contain aerosol cans of pre-cleaner, penetrant, penetrant remover, and developer. Fluorescent systems also contain a black light and require electrical power.

2. Penetrants - Penetrants are classified according to dye type, visible or fluorescent, and by method of removal, water-washable, post-emulsified or solvent-removable.

Visible penetrants contain dyes that are visible under white light. They are available in bright red or green colors that are readily visible against the white developer normally used. Proper lighting of at least 100 foot-candles is necessary to ensure proper visibility of defects. However, even under the best conditions, these penetrants are not as readily visible as the least sensitive of the fluorescent penetrants.

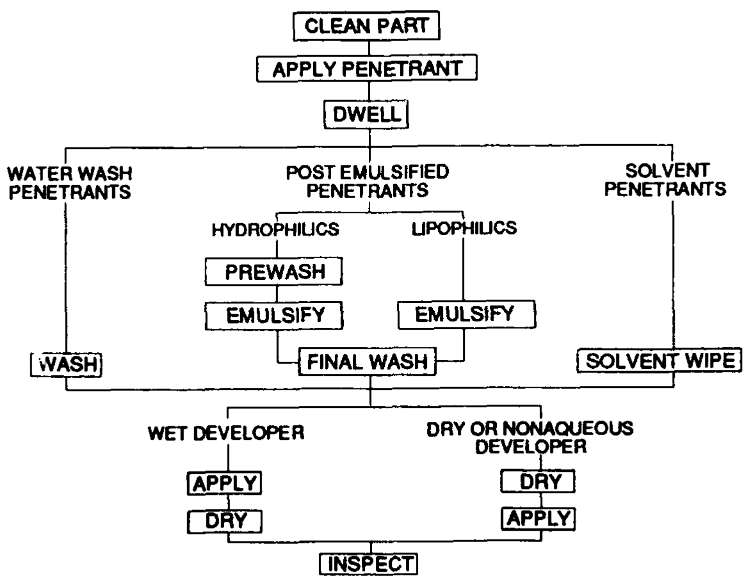


FIGURE 38. BLOCK DIAGRAM OF THE PENETRANT PROCESS

Fluorescent penetrants glow when exposed to light having wavelengths of about 360 nanometers. This characteristic makes very small defects visible when the part is inspected under ultraviolet light in a darkened area. Standard black lights are used in shrouded or darkened booths, with 2 foot-candles or less of background lighting. Visible penetrants can leave residues in the defects that are not compatible with fluorescent penetrants. Consequently, fluorescent penetrants cannot be used in conjunction with, or after, a visible penetrant inspection unless proper cleaning has been accomplished.

Water-washable penetrants combine an emulsifier with the penetrant to make it miscible with water. Without this emulsifier, the oil-based penetrant could not be removed by water. The key process in penetrant inspection is the removal of the excess penetrant without the removal of the penetrant in the defects. After the penetrant has been applied and sufficient dwell time has elapsed, the excess penetrant is removed by washing the surface with clean water. The length of time and the pressure of the spray during the wash cycle is critical to ensure that over washing does not occur.

Post-emulsified penetrants require the application of an emulsifier, if water is to be used to remove the excess penetrant. The emulsifiers are applied directly to the penetrant on the part after the proper dwell time has elapsed. Emulsifiers can be either lipophilics or hydrophilics.

Lipophilics are oil-based emulsifiers that contain solvents. While the emulsifiers are in contact with the penetrant, the solvent action reduces the penetrant and makes it water-washable. The amount of time that the emulsifier is in contact with the part is critical. If left in contact too long, the emulsifiers will dissolve the penetrant in the defects, as well as the excess on the surface.

Hydrophilics are water-based emulsifiers that contain a surfactant. They require some agitation while they are in contact with the penetrant and depend more on scrubbing action than on the dissolving action of solvents. They are less susceptible to over-emulsification than the lipophilics. However, because they have a lower tolerance for penetrant contamination, a prewash step is usually performed to remove some of the excess penetrant with a water spray. Use of hydrophilics is considered the most consistent and reliable of the removal processes.

Solvent-removable penetrants require the use of a solvent for removal. In many cases, such as field operations, it is not possible or practical to utilize water to remove the excess penetrant. With these penetrants, a common solvent is used to wipe the excess penetrant from

the part. Dipping or pouring cannot be used since the solvent will remove the penetrant from within the defects. The penetrant must be removed by meticulously wiping with dampened rags. This process is time consuming and is normally used only on localized areas or when other means are not practical.

3. Developers - Once the excess penetrant has been removed, the penetrant remaining in the defects must be drawn to the surface. This is accomplished with developers that act as blotters, soaking up the penetrant and spreading it on the surface. These developers are classified as either wet, dry or nonaqueous.

Wet developers may be applied while the part is still wet from the final wash cycle. They consist of blotting materials that are either dissolved or suspended in water. Wet developers are applied to cover the whole part and then let to dry. While drying, the water evaporates, leaving a thin coating of the developer. Care must be taken to ensure that puddling of the developer does not occur. Too thick a coating will obscure indications. If it is a suspended solution, it must be periodically stirred to ensure uniform distribution of the developer material. Periodic checks must be made to ensure the proper concentration of the developer. Wet developers are not normally used with water-washable penetrants because the water in the developer may continue the penetrant removal process. In this case, the penetrant could be removed from the defects or be diluted to the point of ineffectiveness.

Dry developers are fluffy white, highly absorbent dry powders, similar to talcum. They are applied after the drying cycle of the final wash cycle since the part must be dry to prevent caking of the developer. A thin film of powder is put on the part by blowing a dust cloud around it. The powdered film should totally cover the areas to be inspected and should be kept dry and free of any penetrant contamination.

Nonaqueous developers are powders that are suspended in a volatile carrier. After being sprayed on the dried part, the volatile carrier immediately evaporates leaving a thin coat of developer. These are the most sensitive developers and work well on localized areas but are more difficult to apply over large areas. The use of these developers requires adequate ventilation.

Indications. The different types of penetrants offer varying levels of sensitivity. The level of sensitivity that should be used depends on the application. Critical parts that cannot withstand the smallest of defects require the most sensitive penetrants. Routine parts and general hardware would require less responsive penetrants.

Aside from flaw size, other factors may affect the penetrant choice. Rough surfaces, such as castings, present a problem of removal for the higher sensitivity penetrants. A less sensitive penetrant would produce less background indications so defects would stand out more clearly. The level of sensitivity or type of penetrant to be used will generally be specified in the OEM manuals or the operating procedures. The classification of specific penetrant types into levels of sensitivity may be made by the OEM, the airline, or by the U.S. Air Force in their Qualified Products List of Mil-Std-25135.

When fluorescent penetrants are used, parts must be inspected in a darkened area to allow small defects to be seen. The inspector should allow time for his eyes to become accustomed to the dark before inspecting the parts. Ultraviolet light is used to cause the penetrant to fluoresce. The intensity of the black light emission should be controlled to ensure adequate fluorescence.

Part Preparation/Safety. It is very important that the part be clean and free of all foreign materials including moisture. Any contamination can block the opening of a defect and prevent the penetrant from entering. All grime, dirt, oil, paint, varnish, oxide or any other contaminant must be completely removed to avoid false defect indications. Because most penetrants are oil based, water is especially detrimental to the process as it will repel the oil and prevent penetration into the defect.

Several safety precautions are necessary when performing penetrant inspection. Penetrants and solvents can cause skin irritation, so contact with clothes and skin should be avoided. Eye protection should be worn when there is risk of splashing. Adequate ventilation must be provided since vapors may be toxic or volatile. Inhaling excessive amounts of dry developers should also be avoided.

DEFECTS SOUGHT. Penetrant inspection is a reliable and inexpensive method for finding surface cracks on many different materials. It will also locate seams, pitting, and porosity at the surface.

METHOD CHARACTERISTICS.

Minimum Detectable Flaw Size. The blotting action of the developer forms an indication that is much wider than the actual defect. This makes it possible to see small defects that would normally go undetected by the eye.

Advantages. The advantages of penetrant inspection include its relative ease of defect interpretation, its ability to be applied to

parts with complex shapes regardless of defect orientation, and its general low equipment costs.

Disadvantages. The major disadvantage of penetrant inspection is its limitation of detecting only surface breaking defects. Thorough part cleaning is necessary, before and after inspection, and it is not suitable for use on porous materials. Also, development time between 10 and 30 minutes is required.

Probability of Detection/Probability of False Alarm. POD with penetrant inspection is fairly high. Easy interpretation of indications makes it a reliable method for finding surface cracks. However, proper part preparation is necessary to ensure reliability.

Inspection Rate. It is necessary to allow 10 to 30 minutes for the developer to draw the penetrant out of defects. Processing can be accelerated by automation of the cleaning, penetrant application, and developer application phases. Inspection, however, must be performed manually.

Training. The reliability of penetrant inspection depends on the ability of the operator to properly prepare and inspect the part. Interpretation of indications, however, is somewhat easier than with other methods.

Portability. Penetrant inspection systems range from highly portable kits to stationary processing systems. The portable kits contain cleaners, penetrants and developers that can be sprayed or brushed onto the parts, without having to remove the parts from the aircraft.

TYPICAL EQUIPMENT USED TO INSPECT AIRCRAFT. Penetrant inspections performed by the airlines consist of conventional "dye-check" inspections performed on the airplane and fluorescent penetrant inspections performed on parts removed from an airplane during overhaul.

Dye-check is the most common penetrant inspection performed on an airplane. Dye-check inspection is accomplished using a visible red dye and requires the use of solvent, cleaners, and a developer. Most airlines use a dye-check kit that consists of the required chemicals in convenient spray cans. Two major sources of visible penetrant kits used by the airlines are:

Met-L-Check　　　　Ardrox/Tracer-Tech

The fluorescent penetrant process is generally performed in a permanent facility consisting of several large tanks of chemicals and cleaners and a controlled light area for viewing parts under black light. These kits are available from many different sources. Two manufacturers of fluorescent penetrant systems are:

Magnaflux Corp. Ardrox/Tracer-Tech

MAGNETIC PARTICLE.

DESCRIPTION OF METHOD.

General. Magnetic particle inspection is used to detect surface and subsurface discontinuities in materials that are readily magnetized. This NDI method is commonly used to inspect steel fasteners, landing gear components, and other steel components such as engine and empennage attach fittings. Magnetic particle inspection provides excellent indications of all surface discontinuities provided that the part is free from grease, oil, dirt, loose scale or surface finish. Consequently, this type of inspection is generally applied to parts which are disassembled from the aircraft. Generally, alternating current is better at detecting surface defects and direct current is more effective in finding subsurface defects.

1. Magnetic Fields - When ferromagnetic parts are exposed to an electrical current or magnetic field, a similar field will be induced within the part. These fields become distorted in the vicinity of a discontinuity or defect. The direction of the magnetic field is critical to the detection of flaws. For best results, the lines of magnetic force should be at right angles to the longest dimension of the defect. By controlling the direction of the magnetizing current, the lines of magnetic force can also be controlled. A general rule for magnetic field orientation is the "right-hand" rule. This rule states that if you grasp the article being magnetized with your right hand so that your thumb points in the direction of current flow, the

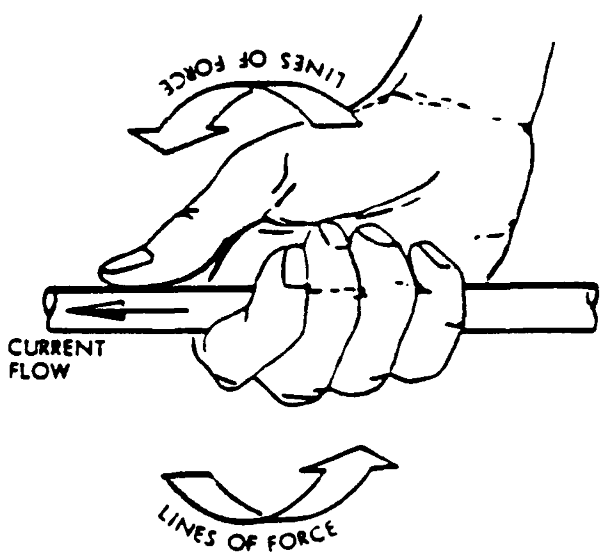


FIGURE 39. THE RIGHT-HAND RULE

direction of the lines of force in the magnetic field will be represented by your four fingers (see figure 39).

Longitudinal magnetism is achieved by current-carrying coils which encircle the part and induce a longitudinal field (see figure 40). The effective magnetic field extends from 6 to 9 inches from each end of the coil and longer parts can be magnetized in sections by moving the part through the coil.

Circular magnetism is achieved by applying the electrical contacts at each end, or each side of the area being inspected and allowing the current to flow through the part (see figure 41). Where the part is too large to apply end contacts, the part can be magnetized with clamp contacts.

2. Magnetization Current - Direct current, alternating current and many rectified forms of current are suitable for magnetizing purposes.

Direct current produces magnetic fields which penetrate the cross section of the part, providing detection of subsurface defects.

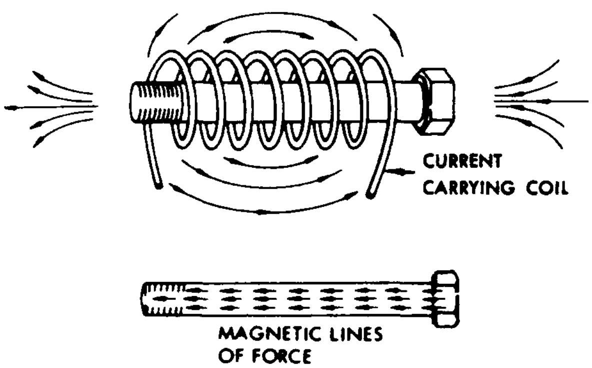


FIGURE 40. ILLUSTRATION OF LONGITUDINAL MAGNETISM

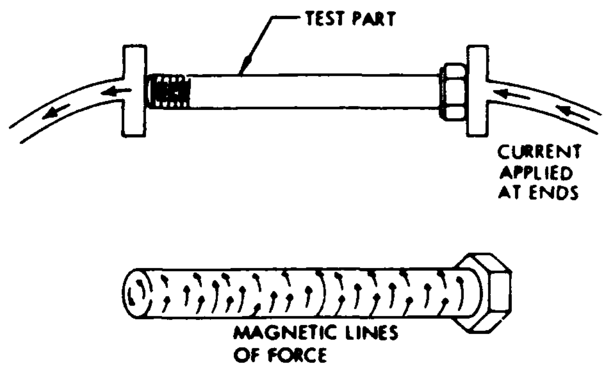


FIGURE 41. ILLUSTRATION OF CIRCULAR MAGNETISM

Alternating current (figure 42) produces a magnetic field that is confined almost entirely to the surface of the part. This phenomenon, known as "skin effect", occurs at high frequencies (above 50 Hz) and makes alternating current useful only for defects at or near the surface of the part.

Direct current that is rectified from alternating current is useful for many purposes. Half-wave rectified single-phase (figure 43) produces very sensitive fields with little skin effect. Full-wave rectified single-phase (figure 44) is similar to half-wave, but uses more power to produce a given magnetizing effect. Three-phase

rectified alternating current (figure 45) is equivalent to direct current for the purpose of magnetic particle inspection.

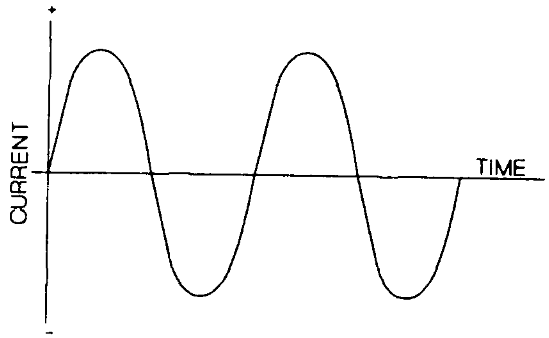


FIGURE 42. SINGLE-PHASE ALTERNATING CURRENT

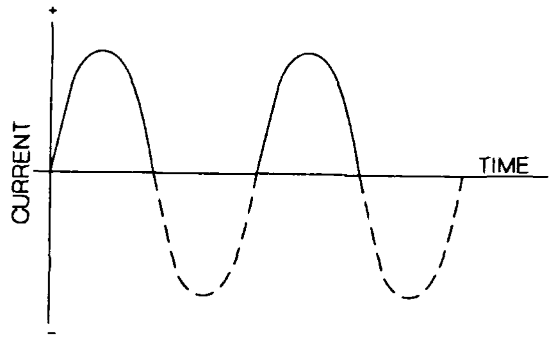


FIGURE 43. SINGLE-PHASE HALF WAVE RECTIFIED CURRENT

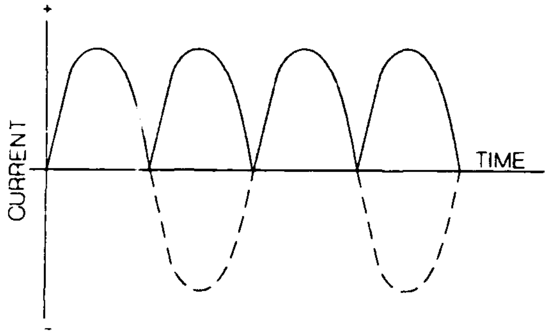


FIGURE 44. SINGLE-PHASE FULL-WAVE RECTIFIED CURRENT

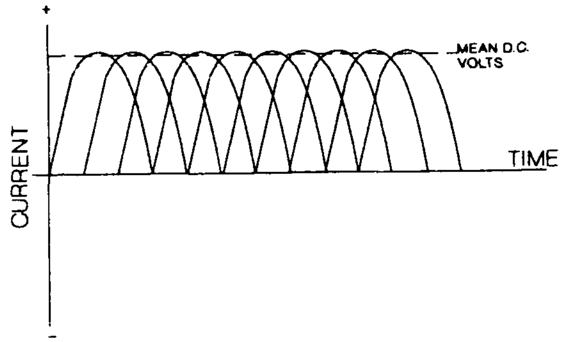


FIGURE 45. THREE-PHASE FULL- WAVE RECTIFIED CURRENT

3. Magnetization Level - It is important in magnetic particle inspection to apply the proper field strength. Too weak a field will not hold enough particles to provide satisfactory indications. Too strong a field will hold too many particles and flaw indications can be masked by background indications. Fortunately, a considerable range is permissible in most cases. Experience will often determine the best way to properly magnetize a part. Generally, one or more of the following methods will be used to determine the proper magnetic field strength:

Use of formulas (which usually applies only to simple geometry).

Use of a test part containing defects of the size and type sought. Test piece geometry must be very similar to the actual part and it must be manufactured with the same material and processing steps.

Use of a gaussmeter to measure the tangentially applied field strength at the surface of the part. Field strengths in the range of 30 to 60 gauss are normally adequate.

4. Demagnetization - All ferromagnetic materials will retain some residual field after magnetization. This field may be very weak in soft materials and quite intense in harder materials. Demagnetization is necessary if the retained field would interfere with the operation of the part or the instruments around it, such as a magnetic compass. Also, the residual field could retain particles that might prevent proper cleaning, plating, or painting after the inspection.

Demagnetization is usually accomplished by subjecting the part to a continually reversing field which is gradually reduced in strength.

Equipment. The two major components of any magnetic particle inspection are the field inducers and the particles.

1. Magnetic Field Inducers - Methods of inducing magnetic fields in test parts include use of hand-held yokes, prods, clamps and various coil configurations. Equipment can be energized by power units ranging from 115 volts AC to 440 volts triple-phase. The larger units are capable of generating in excess of 10,000 amps at low voltage, which is necessary for inspection of large castings, weldments, and forgings.

2. Magnetic Particles - During or after magnetization of the part, the flaw or discontinuity is made visible by covering the area with magnetic particles that align themselves along the flaw or discontinuity. The particles are made of carefully selected magnetic materials of proper size, shape, magnetic permeability, and retentivity. There are two types of magnetic particles used in magnetic inspection, wet particles and dry particles. The particles may be colored to provide better contrast with the surface being inspected, or have a fluorescent coating for viewing with a black light. Wet particles consist of a suspension of magnetic particles in water, light petroleum distillate, or light oil. They are applied by dipping or immersing the part in the solution, or by delivering it to the part by a shaker. Dry particles are in powder form and are borne by air. They are applied using hand shakers, spray bulbs, shaking screens, or an air stream.

Indications. Flaws are detected by observing the particle pattern formed on the surface of the part being inspected. The approximate size and shape of the flaw is disclosed by this pattern. As shown by figure 46 and figure 47, flaw orientation can significantly affect detection. Permanent records of indications can be made by photography, lacquer-fixing or tape transfer. The characteristics of wet, dry and fluorescent particles follow:

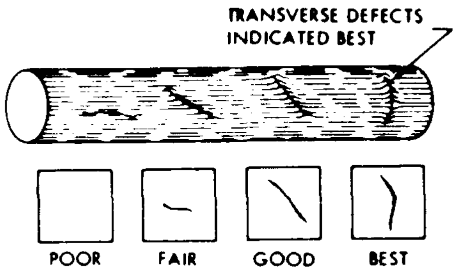


FIGURE 46. LONGITUDINAL MAGNETIZATION DEFECT INDICATIONS

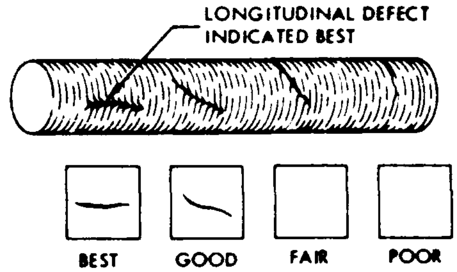


FIGURE 47. CIRCULAR MAGNETIZATION DEFECT INDICATIONS

1. Wet Particles - Wet particles give the best indications of very fine, shallow, surface cracks. When used in a bath, they will quickly and thoroughly cover all surfaces of irregularly shaped parts. Also, they can cover a large number of small parts at once. In addition to a bath, particles can be dispensed from spray cans or small portable shakers. However, wet particles are not usually capable of finding defects lying more than a few thousandths of an inch below the surface.

2. Dry Particles - Dry particles work best on rough, horizontal surfaces, and are often used with portable equipment. They are excellent for locating subsurface defects. They have good mobility when used with alternating or half-wave current, however, they do require care during application to ensure even dispersal.

3. Fluorescent Particles - Fluorescent particles are usually wet particles that have been coated with a fluorescent dye to provide a faster, more reliable inspection. Fine discontinuities will develop more readily discernible indications when formed with the fluorescent magnetic particles. Smaller flaws, flaws in corners, threads and keyways become more clearly visible. Fluorescent particles must be viewed under black light with the recommended minimum lighting intensity of 1000 micro-watts per square centimeter. Significant increases in visible brightness of fluorescent particles can be achieved for black light intensities up to 4000 micro-watts per square centimeter. However, there are safety concerns when ultraviolet light incident on the eye and skin exceeds 1000 micro-watts per square centimeter.

<u>Part Preparation/Safety.</u> Parts must be free from grease, oil, rust, scale, paint, or other substances which can affect magnetic particle inspection. The following precautions must be observed during inspection:

1. Use only approved solvents, especially if the part being inspected is heat-treated steel.

2. Keep cleaning fluids or magnetic particles out of areas where they could be entrapped.

3. Remove dissimilar metals such as bushings, bearings, and inserts prior to cleaning and inspection.

4. Do not magnetize bearings.

5. Avoid arc strikes when passing current through critical parts which could be damaged.

DEFECTS SOUGHT. Magnetic particle inspection is the best method for finding surface cracks on ferromagnetic materials. These materials include iron, steel, cobalt, and nickel. Nonferrous materials, such as aluminum, magnesium, copper, lead, tin, titanium and ferrous austenitic stainless steels cannot be inspected. Principal applications include:

Flaw Detection. Surface and subsurface defects, cracks, .seams, porosity, stress corrosion and inclusions can be detected by magnetic particle inspection. It is extremely sensitive to small tight cracks on the surface of ferromagnetic parts.

METHOD CHARACTERISTICS.

Minimum Detectable Flaw Size. Wet particles are capable of detecting fatigue cracks of a depth less than 0.001 inch and a surface opening of perhaps one tenth that or less.

Advantages. The advantages of magnetic particle include its ability to detect very fine surface and subsurface detects. Inspections can be performed rapidly and at low cost. In most cases, the equipment is highly portable and can inspect almost any size and shape part. Interpretation of defect indications requires no special training.

Disadvantages. The disadvantage of magnetic particle inspection is that it can only be used on ferromagnetic parts. Proper alignment of magnetic field and defect is critical to ensure proper inspection and demagnetization is usually required after inspection. Cleaning is necessary both before and after inspection and some indications can be masked in the presence of some surface coatings.

Probability of Detection/Probability of False Alarm. Magnetic particle inspection is the most reliable method for finding small, tight cracks on the surface or slightly below the surface, of ferromagnetic materials. If field orientation, field strength,

current and particle type are all matched to the suspected defect, excellent results will be obtained.

Inspection Rate. Magnetic particle inspection yields immediate results. Results will be visible on the part as soon as the field and particles are applied.

Training. Interpretation of magnetic particle results is relatively simple, however, inspection setup, magnetization and demagnetization should be performed by qualified personnel who are acquainted with the equipment and procedures.

Portability. Magnetic particle equipment is highly portable. Most systems are hand-held and weigh from 5 to 20 lbs.

TYPICAL EQUIPMENT USED TO INSPECT AIRCRAFT. Magnetic particle inspection of airplane structure is accomplished either on the airplane using portable magnetizing equipment or off the airplane during major overhaul when large steel parts are removed.

Magnetic inspections of parts installed on the airplane are generally accomplished using a portable magnetic yoke. Magnetic yokes are essentially large adjustable horseshoe shaped magnets that are used to induce a magnetic field in a relatively small area of a part between the legs of the horseshoe. Large parts are inspected by repeating the magnetization and inspection operations until the entire part is covered. Two sources of magnetic yokes used by the airlines are:

Parker Contour Probe DA-200 (requires line power)
Parker Research Corp.

Y-6 Magnetic Yoke (requires line power)
Y-5 Magnetic Yoke (permanent magnet, no power required)
Magnaflux Corp.

When steel parts are removed from the airplane, they are inspected in a fixed magnetic inspection facility. Most airline overhaul bases have permanently installed magnetic bench equipment with the electrical and physical capability to inspect the largest landing gear components. Examples of fixed magnetic bench installations are:

84 inch AC/DC bench
Magnaflux Corp.

114 inch AC/DC bench
Ardrox

AIRCRAFT INSPECTION APPLICATIONS

AIRFRAME INSPECTIONS.

INTRODUCTION. The airlines use a wide variety of NDI methods to supplement the periodic visual inspections performed on commercial airplanes. Generally, these inspections are developed by the airframe or engine manufacturers and detailed NDI procedures are published in the manufacturers' NDI manuals, which are distributed to the airlines.

The Air Transport Association specification ATA-100 defines the content and organization of the manufacturers' NDI manuals. The manuals contain some general NDI information, but are primarily a collection of NDI procedures specific to particular airplane models. The manuals are divided into major chapters, each devoted to a specific NDI method.

The NDI manuals provide the details of how to perform specific inspections. The manuals do not contain information on inspection intervals, repair, or what model line numbers require inspection. This information is contained in other documents, such as manufacturers' service bulletins or maintenance plans. In some situations an NDI requirement may be defined only by FAA Airworthiness Directive.

Following are descriptions of some typical NDI inspections performed by the commercial airlines. Actual examples of some of the techniques used may be found in appendices A, B, and C.

FUSELAGE.

Fatigue Cracking At Fuselage Skin Fastener Holes. The components of a commercial aircraft, including the fuselage section, are shown in figure 48. The most common NDI technique used for detecting small cracks in the fuselage skin emanating from fastener holes uses a high frequency eddy current pencil probe. A guide such as a circle template is used to ensure that the pencil probe scans uniformly around each fastener. This procedure readily detects 0.10 inch or longer cracks. Smaller cracks can be reliably detected if fixturing is used to accurately position the inspection scan. See appendix A, Technique 1.

Many airlines are using a low frequency eddy current sliding probe technique to inspect the aircraft skin along rows of identical fastener holes. The inspection requires the use of a straight edge to ensure that the probe passes over the center of each fastener in the row. The inspection is presented on the screen of an eddy current

impedance plane instrument. The inspector must compare the complex signal obtained at each fastener location with the signals obtained from other fasteners and with a calibration standard. The sliding probe technique readily detects cracks 0.10 inch or longer in the outer skin. A similar technique may also be used for detecting cracks in the inner skin at lap splices or similar doubler locations. Use of the sliding probe greatly reduces inspection time in situations where hundreds or thousands of identical fasteners require inspection. See appendix A, Technique 2.

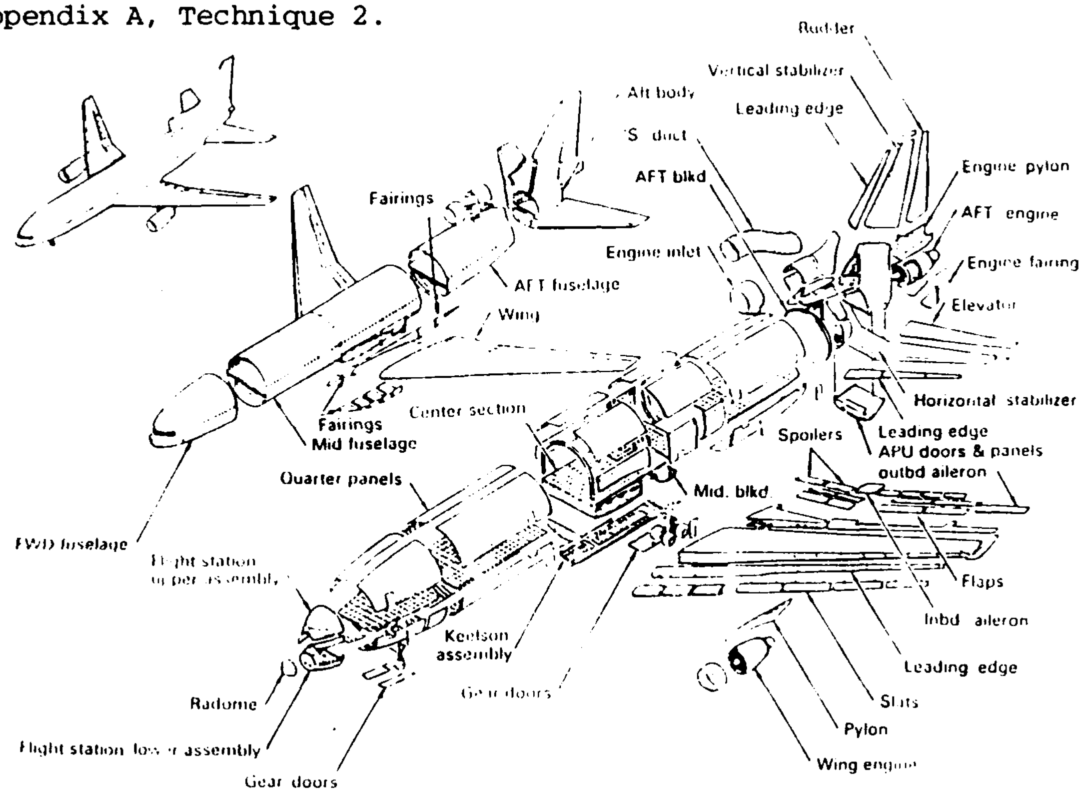


FIGURE 48. COMMERCIAL AIRCRAFT COMPONENTS
Courtesy of McDonnell Douglas Corp

<u>Fatigue Cracking of Stringers, Frames, and Doublers.</u> Large cracks or broken parts can generally be detected by x-ray. The inspection is normally accomplished by taping x-ray film to the outside skin surface, and positioning the x-ray tube inside the fuselage. When x-raying the crown of the airplane, it is common practice to position a long strip of film circumferentially over the crown and "shoot" several different stringer/frame connection points simultaneously. See appendix C, Technique 1 and 2.

A low frequency eddy current sliding probe procedure can be used to detect cracks in the stringers by inspecting through the fuselage skin. In this procedure, the probe is slid along the row of rivets common to the skin and stringer. The inspection detects cracks in the

stringer approximately 0.25 inch long and greater. See appendix A, Technique 2.

Stress Corrosion Cracking of Body Bulkhead Fittings. Stress corrosion cracks may occur in thick section parts made from 7079-T6 aluminum alloy that was used extensively in older commercial airplanes.

Visual, penetrant (dye-check) or surface eddy current inspection procedures may be used to inspect for cracks that break accessible surfaces. In situations where large stress corrosion cracks propagate internally or do not break an accessible surface, ultrasonic inspection may be used. An ultrasonic beam is directed into the part from a transducer placed directly on the surface. If a crack interrupts the ultrasonic beam, it may either reflect back to the transducer or interfere with the back surface echo, alerting the inspector to the possibility of a large internal crack.

Corrosion of Outer Skin. Corrosion loss on the inner surface of the outer fuselage skin can be detected and estimated with low frequency eddy current inspection. In this inspection, it is essential that the operator select an eddy current operating frequency that just penetrates the outer skin, but does not penetrate any underlying doublers or fittings. A calibration standard of the same thickness as the skin being inspected and with simulated corrosion loss is essential. The low frequency eddy current procedure will reliably detect and estimate corrosion loss of 10 percent of the outer skin thickness and greater. See appendix A, Technique 3.

Ultrasonic thickness gauges are not recommended for inspecting corrosion loss as they measure only flat reflective surfaces and do not detect the intergranular cracking associated with moderate to severe corrosion.

Disbonding of Skins and Doublers. There are several ultrasonic instruments specifically designed for inspecting bonding that will reliably detect disbonds in metal to metal or composite structure. None of the instruments can be used to determine or compare bond strength.

Most ultrasonic instruments require a liquid couplant to get sound energy from the transducer into the test piece. Some bond testers, however, operate at a low enough frequency that liquid couplant is not required. This is a distinct advantage w' ·n inspecting large aircraft surfaces.

Fuselage skin to doubler bonding can be inspected by sliding an ultrasonic transducer over the fuselage surface. Disbonds are indicated by a change in a meter reading, a scope presentation or an audible signal heard in a head set, depending on the instrument used. Minimum detectable disbonds vary from approximately 0.375 to 1.0 inches in diameter depending on the instrument, the probe used, and the thickness of the skin doubler assembly being inspected. See appendix B, Technique 2. However, this method is not entirely effective when the lap joints are held together tightly with rivets.

WING AND EMPENNAGE STRUCTURE.

Splice Plate or Stringer Cracks. A typical aircraft wing structure is shown in figure 49. Large cracks in second layer structure, such as splice plates, stringers, or the horizontal flanges of spar chords, can be detected by x-ray provided that the part being inspected is thick enough to allow adequate contrast on the film and that the x-ray tube and film can be positioned correctly. In most situations, however, low frequency eddy current is a more practical method for inspecting cracks in second layer wing structure.

Low frequency eddy current techniques are used to inspect through wing skins up to 0.375 inches thick, and occasionally thicker in special situations. The inspections are either accomplished using an encircling probe placed over the fasteners common to the skin and second layer structure or, with thinner wing skins, a "spot" probe is placed on the skin between fasteners to detect large cracks in the underlying structure. The greatest penetration is achieved with encircling probes operating at 100 Hz. "Spot" probes operated at 500 Hz will detect cracks on the order of 1.0 inch long beneath 0.25 inch thick wing skins.

The airlines prefer to use low frequency eddy current inspection procedures in lieu of x-ray to avoid the health risk involved with x-ray. It is necessary to clear all maintenance personnel other than the x-ray technicians from an airplane and usually the hangar when performing an x-ray inspection. There are no health risks associated with eddy current inspection, which is generally performed simultaneously with other maintenance activities.

Broken or Cracked Bolts. When a bolt breaks in service it generally remains in place, held firmly by sealant, surface corrosion, and structural loads. It is difficult and expensive to inspect any significant number of installations by the remove and replace method.

Many airlines are using ultrasonic inspection to check installed bolts in critical structure. The simple ultrasonic inspection consists of

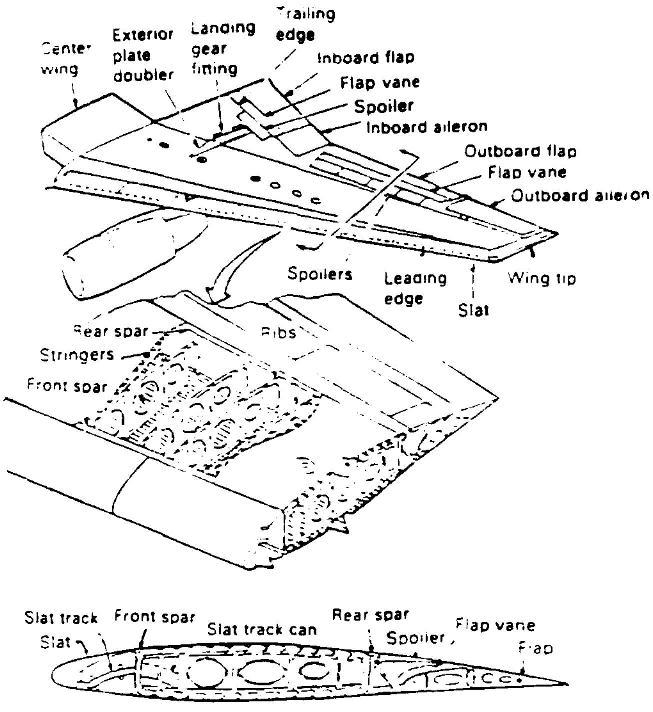


FIGURE 49. COMMERCIAL AIRLINER WING STRUCTURE
Courtesy of McDonnell Douglas Corp.

placing a transducer on the end of the bolt and obtaining an echo from the opposite end. The return echo appears on a time-base oscilloscope in a position corresponding with the length of the bolt. Broken bolts or large cracks are indicated by signals shorter than or ahead of the calibrated bolt length. See appendix B, Technique 1.

Fatigue or Stress Corrosion Cracking of Attachment Lugs. Ultrasonic inspection is commonly used to inspect for cracks initiating at the connecting pin hole of attachment lugs such as those used to hold engine struts or landing gears. A typical lug has a curved surface and it is necessary to use a curved transducer "shoe" with grease or oil to couple the ultrasound into the part. The transducer shoe is generally made of lucite and shaped so that the angle between the transducer and surface of the part refracts the ultrasonic beam. A refracted longitudinal wave or shear wave may be used depending on the beam direction needed in the part. This type of ultrasonic inspection will reliably detect cracks on the order of 0.050 inch deep. Figure 50 illustrates an ultrasonic inspection of a horizontal stabilizer skin plank.

Fatigue or Stress Corrosion Cracks in Fastener Holes. Probably the most well known NDI performed by the airlines is the eddy current inspection of fastener holes in wing structure. The inspection is performed with the fasteners removed and is generally performed during a directed structural modification or repair. The inspection is not applicable to general periodic maintenance programs.

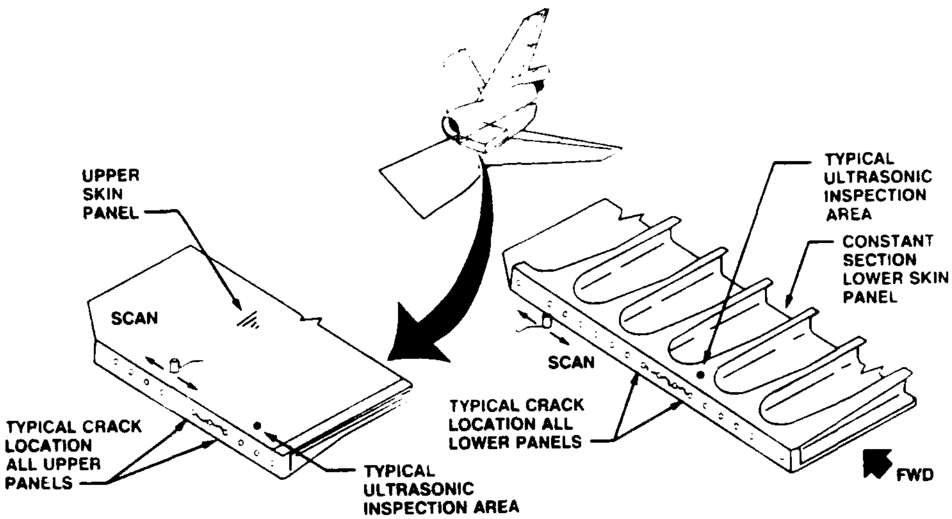


FIGURE 50. ULTRASONIC DETECTION OF CRACKS IN HORIZONTAL STABILIZER SKIN PLANKS

Courtesy of McDonnell Douglas Corp.

Fastener hole inspection is performed with a high frequency eddy current probe inserted into the hole. The probe is rotated with the sensing coil in near contact with the inside diameter surface to detect cracks breaking the inner surface of the hole. If hand held probes are used, the probe must be positioned and rotated at depths of 0.05 inch increments. Newer power driven probes that rotate at high speed make the inspection much easier as it is only necessary to push the probe through the part and remove it to complete the inspection.

The read-out for a hand held probe can be displayed by either a meter or an impedance plane presentation. The read-out for high speed power driven probes is a scope type swept time-base presentation. The eddy current hole technique will reliably detect cracks on the order of 0.030 inch deep in the wall of a fastener hole.

Control Surfaces. The honeycomb structure (either metal or composite materials) used in control surfaces may be subject to periodic inspections. Some of the materials are subject to water ingestion while others may experience disbonding of the composite or metal face sheets.

X-ray is the most practical, reliable method for detecting water ingestion. The x-ray method will readily detect and quantify any significant water in the honeycomb cells and will show any significant core damage.

Ultrasonic bond inspection instruments may be used for detecting disbond of the face sheets. This may be accomplished with a hand-held probe inspecting one surface at a time, or through transmission system

can be used for inspecting both surfaces simultaneously. See appendix B, Technique 2.

LANDING GEAR.

The in-service cracking of a landing gear component may result in a one time on-wing NDI check being called out by a manufacturer's service bulletin. However, the primary NDI checks of landing gears are performed during major overhaul when the gear is removed from the airplane and disassembled. The paint is stripped from the major components, cadmium plating is stripped from steel components, and if it is damaged, chromium plating is also stripped from steel components.

Components made from magnetic steels are given a magnetic inspection while aluminum and other nonmagnetic parts are given a fluorescent penetrant inspection. The magnetic steel parts receive a second magnetic inspection following any rework or replating operations and prior to painting. Figure 51 illustrates typical cracks found in landing gear attachments.

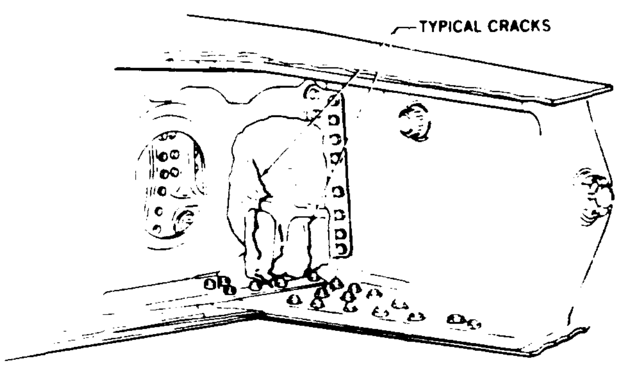


FIGURE 51. CRACKING OF MAIN LANDING GEAR ATTACH FORGING
Courtesy of McDonnell Douglas Corp.

JET ENGINE INSPECTIONS.

INTRODUCTION. The philosophy of jet engine maintenance has undergone significant changes during the last two decades. Prior to the mid 1960's, almost all airlines utilized a hard time engine overhaul concept; that is, engines were torn down and overhauled at specified intervals depending on their service history. Since that time, operators have begun to use reliability programs and sectional overhaul programs. These programs concentrate efforts on the areas of the engine that need attention and recognize those areas that are reliable and do not require tear-down. These programs are defined as:

Hard Time - Items must be removed from service at or before a previously specified time.

On-Condition - Use of repetitive inspections or tests to determine the condition of units, systems, or modules to determine continued serviceability. Action is taken based on results of the tests or inspections.

Condition Monitoring - Use of data from a whole population of specified items to establish maintenance requirements. This procedure allows some failures to occur and relies on experience to dictate need.

Most operators use some combination of these programs. A cost effective system is to use an on-condition or a condition monitored program in conjunction with the refurbishment of specific hardware based on hard time when an engine is removed for cause.

Engine manufacturers publish an overhaul manual that provides inspection recommendations for each engine type and model. However, these are only recommendations. Since each engine is subjected to different service operating conditions, actual inspection intervals are decided by the operators based upon their own service experience. Consequently, this manual deals with generic inspections and schedules that are common to most jets of a particular model.

ON-WING INSPECTIONS. Engine condition monitoring is often accomplished while the engine is still mounted on the aircraft (see figure 52). The following tests have been developed to provide the operator with sufficient data to determine serviceability of an engine:

Preflight. Before each flight a member of the crew does a "walk-around" or cursory visual inspection to find obvious problems such as foreign object damage (FOD) to fan blades, bypass exit area damage,

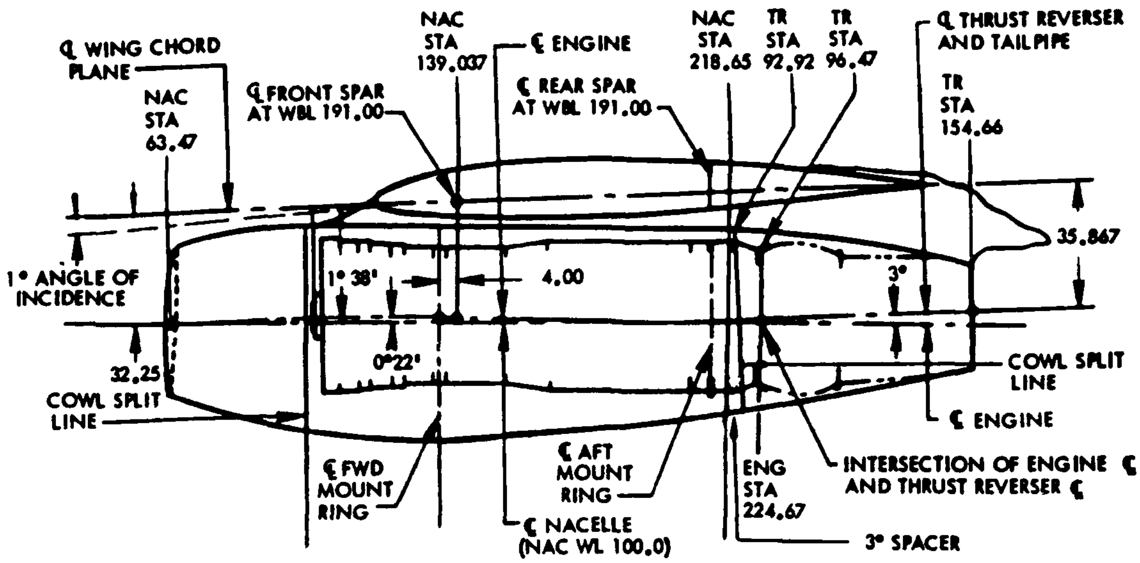


FIGURE 52. TYPICAL TURBOFAN ENGINE INSTALLATION

and any other exterior distress.

Overnight. More detailed inspections are performed periodically when the aircraft is at a maintenance facility for a layover between flights. The frequency and extent of these inspections are based on the individual operator's experience. The following inspections may be performed:

1. Exterior - Exterior tubing is visually inspected to assure all connections are tight, there are no leaks, and tubing is properly secured. Control linkages are examined for proper operation.

2. Compressor and Fan Sections - These areas are visually inspected for FOD. Minor damage may be blended and all repaired areas are inspected for cracks using either dye penetrant or eddy current techniques. Loose fitting blades and other wear conditions are also checked.

Borescopes, as described in the Visual section, may be used to examine the interior of the compressor sections (see figure 53). Compressor blades are checked for cracks, erosion, wear, FOD, and proper positioning of tab locks. Areas checked are dependent on the availability of borescope ports for access and specific engine requirements.

3. Combustion Chamber - Borescope inspection of the hot section is performed to check combustion chambers and surrounding structures for distress. Fuel nozzles, inner and outer ducts, first stage blades and vanes are examined. Figure 54 depicts a cross section of a

typical jet engine with the location of the components discussed. Additional borescope inspections requiring partial disassembly of other turbine stages may also be performed.

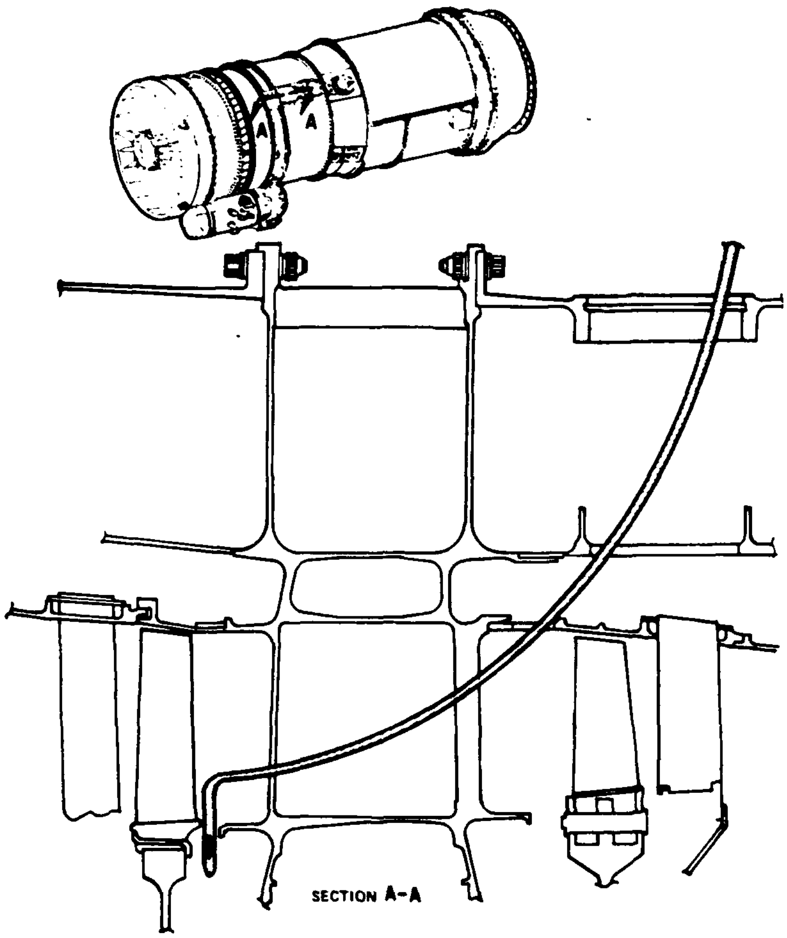


FIGURE 53. BORESCOPE INSPECTION THROUGH ENGINE BLEED PORT

Radiography utilizing isotope equipment (see figure 55) may also be performed to detect cracking, location shifts or other distress in the hot section. A radioactive source is placed within the shaft and film is placed on the outer periphery of the engine to record the images.

4. Accessories - The gearbox is visually checked for oil leaks. The oil system is inspected for oil level and leaks, to assure filters are clean, and to check for metal chips. Metal chips are a symptom of wear of other parts of the engine, especially bearings. If magnetic isolation plugs are installed they are checked for metal particles.

Oil samples are also taken and sent to a laboratory for the Spectrometric Oil Analysis Program (SOAP) for detection of metal particles.

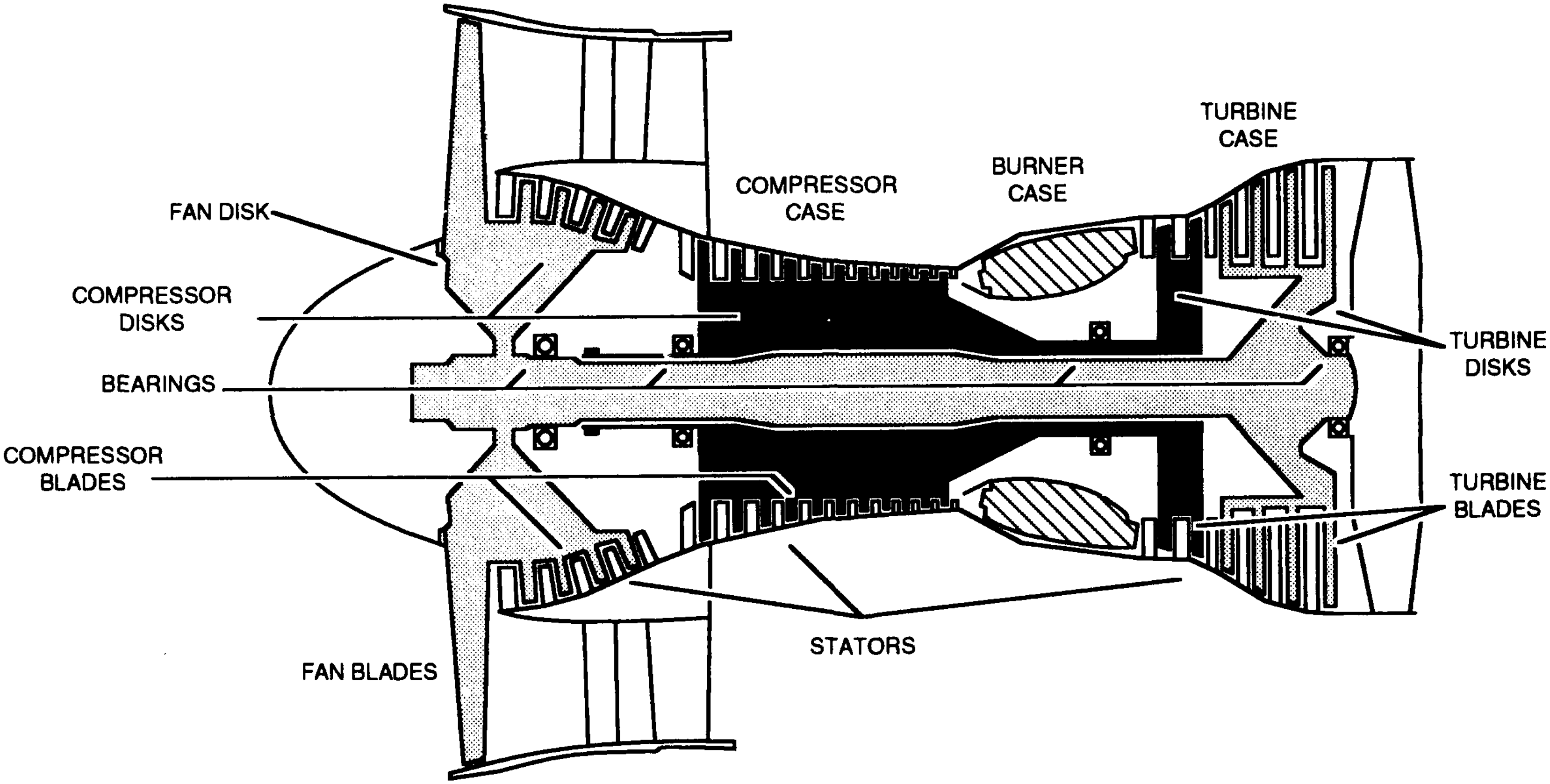


FIGURE 54. TURBOFAN ENGINE COMPONENTS REQUIRING NDI

5. Engine Cleaning - Performance deterioration can be a function of contamination which can result in power stalls, increase rotor speeds, increased exhaust gas temperature, and increased fuel consumption. To prevent this, periodic water spray washing with or without detergent may be performed on the engine gas path, the turbine section, and the fuel nozzles. These cleanings can isolate contamination from other causes of performance deterioration.

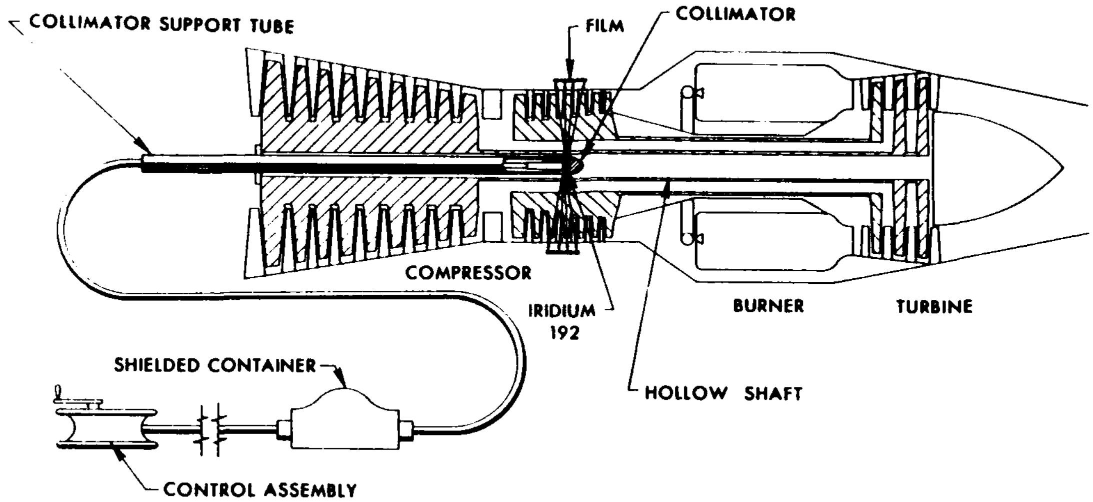


FIGURE 55. ISOTOPE RADIOGRAPHIC INSPECTION OF ENGINE

Condition Monitoring. The general health of a jet engine can be determined by monitoring various parameters related to the gas path. These measurements include:

Low compressor rotor speed
High compressor rotor speed
Exhaust gas temperature
Specific fuel consumption
Thrust
Static pressures
Pressure totals
Temperature totals
Vibration

By analyzing these parameters and studying their interactions, causes for performance loss can be determined and problem areas can be isolated. Performance may be affected by erosion, corrosion, contaminants, distortion, wear of seals, FOD or other factors that can affect flow capacity.

Several programs are available to the operator to track these parameters and to use them for engine condition monitoring. An example of a manual system of in-flight monitoring is the P&W Engine

Condition Monitoring (ECM) Program. With this system, data is taken manually during steady cruise conditions and later fed into a computer program which provides engine condition reports and trend plots. A more sophisticated form of this is the P&W Turbine Engine AIDS Monitoring (TEAM) Program, which is an automated data acquisition system being utilized on newer engines. It takes significantly more data at various times during the flight. It has the ability to isolate module conditions and can better pinpoint trouble areas.

Flight Hours and Flight Cycle Monitoring. Most major rotating parts, some serialized parts, and some turbine parts in jet engines are life limited; that is, they have a finite life and must be removed after a given period of time. Originally the life limits were given in flight hours. As life limits are really based on low cycle fatigue (LCF) data, and the ratio of fatigue cycles to flight hours varies with each operator, flight cycle monitoring is the more accepted criteria. One takeoff and landing is equivalent to one flight cycle or LCF cycle for commercial engines. As part of the condition monitoring above, flight cycles are also monitored. It is important that this information be kept up to date so that short time parts are not rebuilt into an engine. A return to an overhaul facility for removal of the life limited parts would then be required.

Special Inspections. In addition to the routine inspections that are performed there are many specialized inspections generated because of service history. These inspections are usually for given parts in specific engine models and may even be limited to engines with a specified number of flight hours or cycles. They may require a simple visual inspection or a specified nondestructive test procedure such as penetrant, ultrasonics, x-ray or eddy current. They may be invoked by any of the following methods:

1. FAA Airworthiness Directive (AD) - These are issued by the FAA to require an inspection or other action related to a situation that affects flight safety. Operators must conform to these requirements.

2. Manufacturers Alert Service Bulletin - A notification to the airline operators that a particular situation exists and that actions may be taken to avert possible problems.

3. Manufacturers Recommended Service Bulletin - A bulletin by the OEM that a situation exists that may not affect flight safety but may affect engine operation.

The difficulty presented by attempting to apply special inspections to parts in an assembled engine has created some ingenious schemes for applying such inspections. They usually require detailed explanations

and in some cases specialized training and equipment. For example, an Alert Service Bulletin could lead to a specialized ultrasonic inspection which would require an inspector training guide and special fixturing fabricated by the engine manufacturer.

Eddy current and ultrasonics are the two main methods for probing into the engines looking for small cracks not reliably detected with visual methods. Isotopes are used for detection of improperly assembled parts, clearance problems, and for some larger cracks.

OFF-AIRCRAFT INSPECTIONS.

When conditions warrant, the engine is removed from the aircraft and more detailed inspections are performed on the individual parts. The amount of tear-down that is performed is a function of the amount of distress detected, the status of life limited parts, and desire to refurbish for improved performance.

Test Stand Operation. Major airlines that have test stands available to run engines on the ground may choose to take additional data on engine performance to better define the trouble area. Programs similar to the ECM and TEAM for in-flight monitoring are available for test stand data as well.

Hot Section Tear-down. The part of the engine that sees the most distress is the hot section. The high temperatures and air flow create the most damaging conditions. The need to maintain coating integrity on the parts requires more frequent detailed inspections. Even though on-wing borescope inspections provide good visibility, hot sections still require frequent tear-downs because of the greater stresses. Consequently, partial engine tear-downs are performed for the hot section.

The inspections that are performed on the individual parts are visual, penetrant, x-ray, and eddy current. Specific coating thickness tests may be performed for specialized coatings.

A major form of failure of first stage turbine blades is stress rupture and/or creep, the elongation and failure due to high stresses and temperatures over a long period of time. These conditions are more related to flight hours than flight cycles. To monitor this condition, blade length measurements may be made during tear-down. In cases when an engine has seen an over-temperature, blades may be sectioned and metallurgically examined to determine if microstructure has been adversely affected by the excess temperature. To ensure adequate life after reassembly, many parts may need to be refurbished.

This may require replacement of protective coatings and re-examination to ensure proper refurbishment.

Major Tear-down. When conditions warrant, the engine will be brought into the shop for a major tear-down with one or more of the other modules broken down as well as the hot section. The extent of the inspections performed on each part depends on part history, service stress, and criticality. In-flight shutdowns due to minor part failure are cause for concern, but are not catastrophic since aircraft have excess power and can fly with a lost engine. However, failure of major rotor disk parts and fan blades can cause catastrophic events. These parts are large and are difficult to contain within the engine when they fail. The secondary damage they can cause to the aircraft is a major concern and extraordinary attention is applied to these parts. The fuel system can also be dangerous and particular attention must be taken so as to prevent fuel leaks which can cause fires. All parts usually receive at least a visual inspection.

1. Fan Blades - Because of the criticality of the fan blades, they are penetrant inspected and may be eddy current and/or ultrasonic inspected in specific areas. Any refurbishment will have specific inspections applied to the refurbished area.

2. Major Rotor Parts - Major rotor parts are inspected with ultra high sensitivity penetrants. Specific areas with a history of cracking, high stress areas, or difficult areas to see such as bolt holes, may be inspected with eddy current methods. The sensitivity of the inspection is a function of the damage tolerance of the part. Materials that are less tolerant of cracks will have the most sensitive inspection that is practical.

3. Miscellaneous Parts - Many parts that are not stressed in the engine, such as brackets and clamps, will receive only a visual inspection. Other parts that may affect engine operation may receive a penetrant inspection. Parts that are under steady stress and may stretch, such as tie bolts, may be measured to determine serviceability.

Module Replacement. Newer model engines are being fabricated with the modular concept so that disassembly can be performed section by section. For example, the fan sections of many engines may be removed and replaced without removing the engine from the aircraft. This permits extensive repairs to be done without the high cost of engine disassembly. Even when the engine is removed, only the troubled modules have to be disassembled and the engine may be rebuilt with less maintenance time. While the engine is removed, it is

advantageous to refurbish sections to incorporate manufacturer's service bulletins for improved performance and reliability.

NDI METHODS APPLIED TO ENGINE PARTS.

Penetrant Inspection. In an attempt to unify penetrant inspection procedures a consensus document was formulated under SAE auspices by members of the ATA NDT Forum participants. The group included the major engine and airframe manufacturers, the airline operators and the penetrant manufacturers. The resultant document was AMS 2647. The group recognized that penetrant inspection for engine parts was significantly more critical than for airframe inspection and incorporated certain restrictions for engine inspection. Lipophilic emulsifiers are not allowed, closer attention is paid to the processing parameters, and the high sensitivity, non-aqueous developers are normally used for engine parts.

Ultrasonic Inspection. The ultrasonic inspections that are applied are mostly contact methods looking for fatigue cracking in welds, high stress areas of fan blades and other localized areas with known or suspected crack histories. Standard, off-the-shelf electronics are used, but many specialized probes are also fabricated to fit special shapes and to reach difficult areas. Some immersion or bubbler techniques may be used to examine major rotor parts for internal distress and on turbine blades or other areas with thinning problems to verify wall thickness. Sensitivity levels are as necessary to meet part requirements but may be as sensitive as a Number 1 flat bottom hole (0.015 inch diameter) for immersion testing and a 0.003 inch deep slot for contact testing.

Eddy Current Inspection. Eddy current inspection is a localized surface inspection that is utilized only where very high sensitivity is required for specific areas, or where it is difficult to perform penetrant inspections such as in bolt holes. It is very limited in its area of interrogation and requires many scans to do any significant area. Consequently, it is generally used only on specific areas with a history of crack formation.

Radiography. In addition to the radioisotope inspections done on the wing, some x-ray work is done in the shop. It is limited to detecting cracking that is larger than that detected with the other methods, but it does have the ability to inspect in areas difficult for the other methods to access. It works well with thin materials. Resolution for detecting fine cracks has been improved in some applications with the use of microfocus systems.

Visual Inspection. All parts should receive a visual inspection for distress. Inspection should be performed in a well lit area with 100 to 200 foot-candle illumination. For specific areas of concern, magnification of 2x to 10x should be used. In many cases, standards for acceptable conditions and refurbishment limits are provided. General condition of parts may be recorded for future reference.

CONCLUSION

The purpose of this report was to identify and describe the most prevalent nondestructive inspection methods, equipment, and procedures currently in use at aircraft maintenance facilities for the inspection of commercial transport aircraft. As a result, the six most commonly used inspection methods were identified, namely:

- Visual
- Eddy Current
- Radiographic
- Ultrasonic
- Penetrant
- Magnetic Particle

Several aspects of each method were covered including a description of the inspection method, defects sought, method characteristics, and a listing of typical commercial equipment used for aircraft inspection.

In addition to these descriptions, specific NDI applications for both airframe subassemblies and jet engines were presented. Actual NDI procedures pertaining to some of these areas are included in the appendices.

REFERENCES

1. Metals Handbook, Nondestructive Evaluation and Quality Control, ASM International, vol 17. 1989.

2. FAA Advisory Circular AC 43-3, Nondestructive Testing in Aircraft, May 1973

3. FAA Advisory Circular AC 43-7, Ultrasonic Nondestructive Testing for Aircraft, 1975

4. Boeing Inspection Manuals

5. McDonnell Douglas Inspection Manuals

APPENDIX A - EDDY CURRENT INSPECTIONS

LIST OF ILLUSTRATIONS

Technique 1 - Inspection Around Rivet Heads

1. Purpose

To detect cracks extending from the edge of the fastener hole at the base of the countersink out past the rivet head in fuselage skins up to 0.045 inch thick using an oversize template.

2. Equipment

A. Any eddy current instrument that can operate between 100 and 800 kHz and satisfy the performance requirements of this procedure may be used. Instruments with visual and/or audible alarms are recommended. The following equipment was used in the development of this procedure:

1. Locator UH, Hocking Instruments

2. MIZ-10A, MIZ-10B, Zetec, Inc.

3. Magnatest ED-520, Magnaflux Corp.

B. Probe - Shielded probes are recommended. Shielded or unshielded probes may be used provided the calibration notch in the reference standard can be reliably detected. The following probes were used in the development of this procedure.

1. 0.125-inch diameter, 3-inch long shielded pencil probe, P/N MP-30, NDT Product Engineering

2. 0.187-inch diameter, 3-inch long unshielded pencil probe, P/N UP-30, NDT Product Engineering

3. Unshielded Locator probe, P/N 29P101, Hocking Instruments

C. Reference Standard (Figure A-1)

D. Probe Guide - Drafters Circle Template

3. Preparation for Inspection

A. Make sure the inspection area is clean.

B. Locally remove paint only if necessary to locate the rivet heads. Paint removal is not required to perform the inspection.

C. Sand paint locally to remove rough spots only as necessary to facilitate the inspection.

4. Instrument Calibration

A. Do the initial calibration and adjust for lift-off.

B. Put the probe guide on the reference standard.

C. Visually center one of the holes around the rivet head. Choose a hole that positions the pencil probe to scan the edge of the countersink (figure A-2). The hole chosen should give the best detection of the reference notch in the countersink of the reference standard. Identify the hole selected on the probe guide.

D. With the probe guide held firmly in place, scan around the circumference of the rivet head. Monitor the instrument response. The operator should be able to clearly identify the difference between the sudden instrument response from the reference standard crack and the slow instrument response from an off-center condition.

E. Set the instrument sensitivity to clearly identify the reference standard crack so that the needle does not move suddenly off scale as the probe is moved around the fastener head.

F. If the instrument has an alarm, set the alarm to respond to 50 percent of the reference standard notch signal amplitude.

5. Inspection Procedure

A. Identify the fastener location to be inspected.

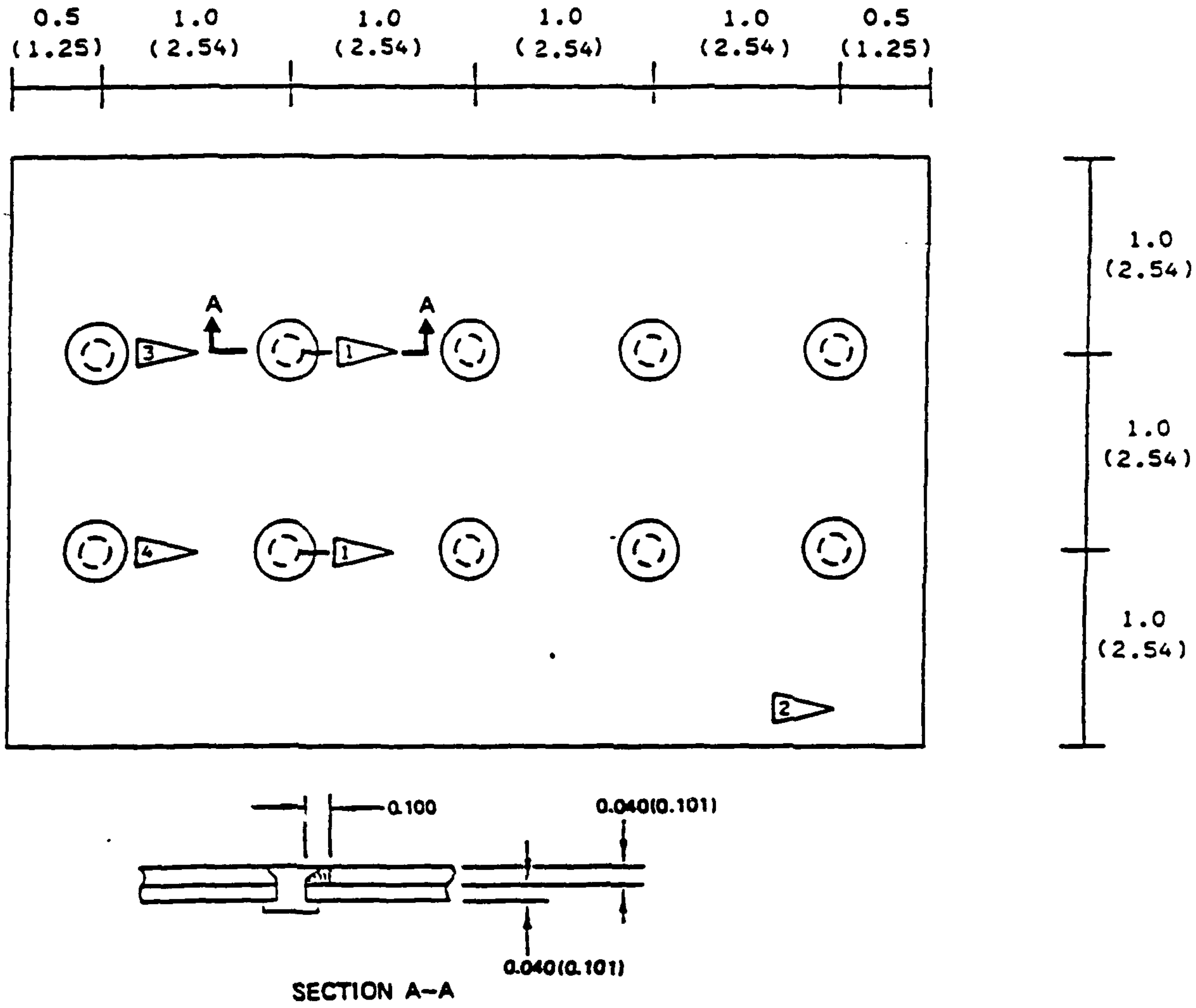
B. Center the probe guide hole from par. 4.C. around the rivet head.

C. Scan around the head with the pencil probe while monitoring the eddy current instrument.

D. Note all locations where a rapid meter deflection, similar to the response from the reference standard notch, is obtained.

6. Inspection Results

A. Cracks can be confirmed by removing the paint and visually checking the crack signal location at 5x or 10x magnification.



- ALL DIMENSIONS ARE IN INCHES (CM IN PARENTHESIS)
- TOLERANCE: X.X±0.05 (0.13)
  X.XXX±0.005 (0.013)
  EXCEPT AS NOTED
- MATERIAL: 2024-T3 OR T4 AL CLAD

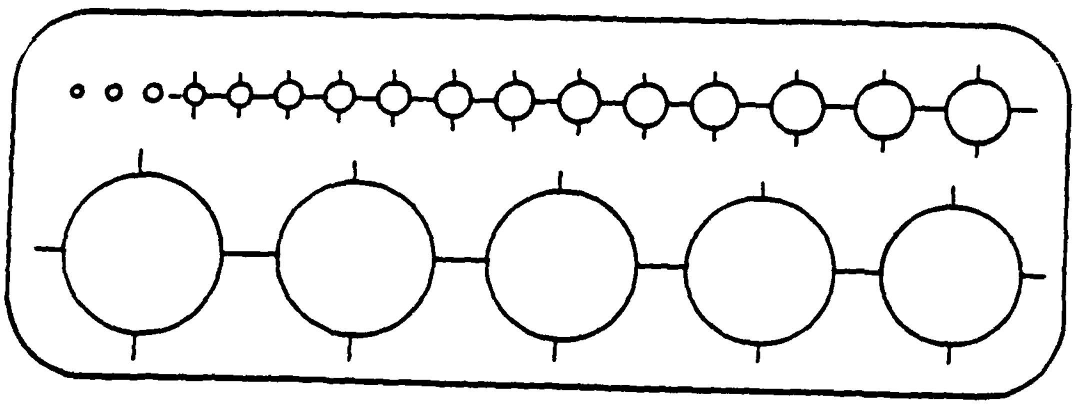
1 EDM NOTCH OR EQUIVALENT 0.007 (0.018) WIDE

2 ETCH OR STEEL STAMP WITH PART I. D.

3 5/32 INCH FASTENERS REQUIRED FOR INSPECTION OF LAP JOINTS

4 3/16 INCH FASTENERS REQUIRED FOR INSPECTION OF CIRCUMFERENTIAL BUTT JOINTS

FIGURE A-1. REFERENCE STANDARD
Courtesy of Boeing Commercial Airplanes



PROBE GUIDE
(DRAFTER'S CIRCLE TEMPLATE)

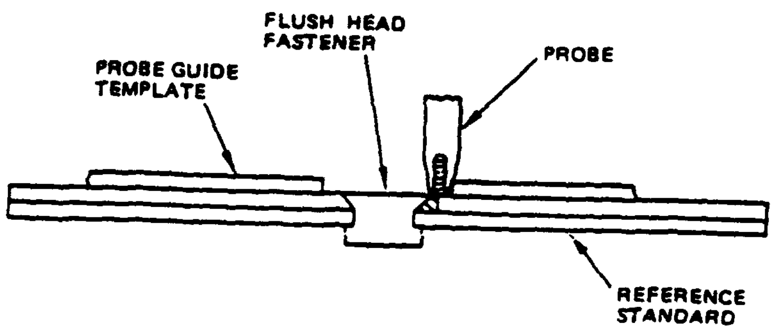


FIGURE A-2. INSTRUMENT CALIBRATION
Courtesy of Boeing Commercial Airplanes

Technique 2 - Low Frequency Eddy Current - Sliding Probe

1. Purpose

The inspection element is located from y=588 to y=803 where Longerons 2 (R&L) and 3 (R&L) attach to the skin. This inspection is performed to detect circumferential fatigue cracks in the fuselage skin and longerons. (See figure A-3).

2. Preparation For Inspection

Clean all dirt, grease, and loose paint from inspection area.

3. General Visual Inspection

A. Perform a preliminary check of the general area for cleanliness, presence of foreign objects, security of parts, cracks, corrosion, and damage.

4. Inspection Sequence 1

A. Equipment/Materials

1. Inspection Method 01

a. Eddy Current Flaw Detector with Flying Dot CRT Capable of Accepting Reflectance Type Probes.

NDT-18, Staveley Instruments or equivalent

b. Reflectance Type Low Frequency Eddy Current Probe Operating at 1 to 5 kHz.

SPO 1958 with 0.3 inch spacer, Staveley Instruments or equivalent

c. Eddy Current Reference Standard - Local Manufacture (See figure A-4 for passenger aircraft)

d. Trichloromethane 1,1,1 or equivalent.

e. Nonmetallic straightedge approximately 2 feet long.

B. Inspection Procedure

1. Inspection Method 01

NOTE: Ensure that spacer located between the red and blue sections of probe SPO 1958 is 0.3 inch wide.

a. Attach probe to eddy current instrument and set operating frequency at 2 kHz for passenger aircraft.

b. Place probe on reference standard and calibrate in accordance with manufacturer's instructions.

c. Using the nonmetallic straightedge, center reflectance probe over the rivet line of the reference standard which simulates the longeron.

d. Scan across the longeron and skin reference EDM notches in the longeron rivet line and adjust the horizontal and vertical gain controls to obtain a scope pattern similar to that shown in Figure A-5 for passenger aircraft.

e. Place straightedge on aircraft so as to center the reflectance probe over the row of rivets at Longeron 2R at Station Y=588. Scan the length of the guide.

f. Move the straightedge to Longeron 3R and repeat e. above.

g. Repeat e. and f. above until entire length of longerons 2R and 3R are inspected from Stations Y=588 to Y=803.

NOTE: Mark area of straightedge coverage to insure complete inspection of longeron(s).

h. Repeat e., f., and g. above until longerons 2L and 3L are completely inspected within the required station locations.

NOTE: Chipped paint in the inspection area(s) may cause erratic probe motion. This condition can be minimized by placing a piece of flexible plastic sheet (Mylar or equivalent) between the probe and the fuselage skin equal to the length of the nonmetallic straightedge. The plastic sheet should be fixed to the straightedge.

PRIOR TO USING THE FLEXIBLE SHEET METHOD, PLACE SHEET OVER REFERENCE STANDARD AND RECALIBRATE EDDY CURRENT INSTRUMENT.

5. INSPECTION RESULTS

A. Any indication is considered a crack, which exhibits the same relative phase angle and an amplitude of 50 percent or greater than that of the reference standard.

B. Crack indications are to be evaluated.

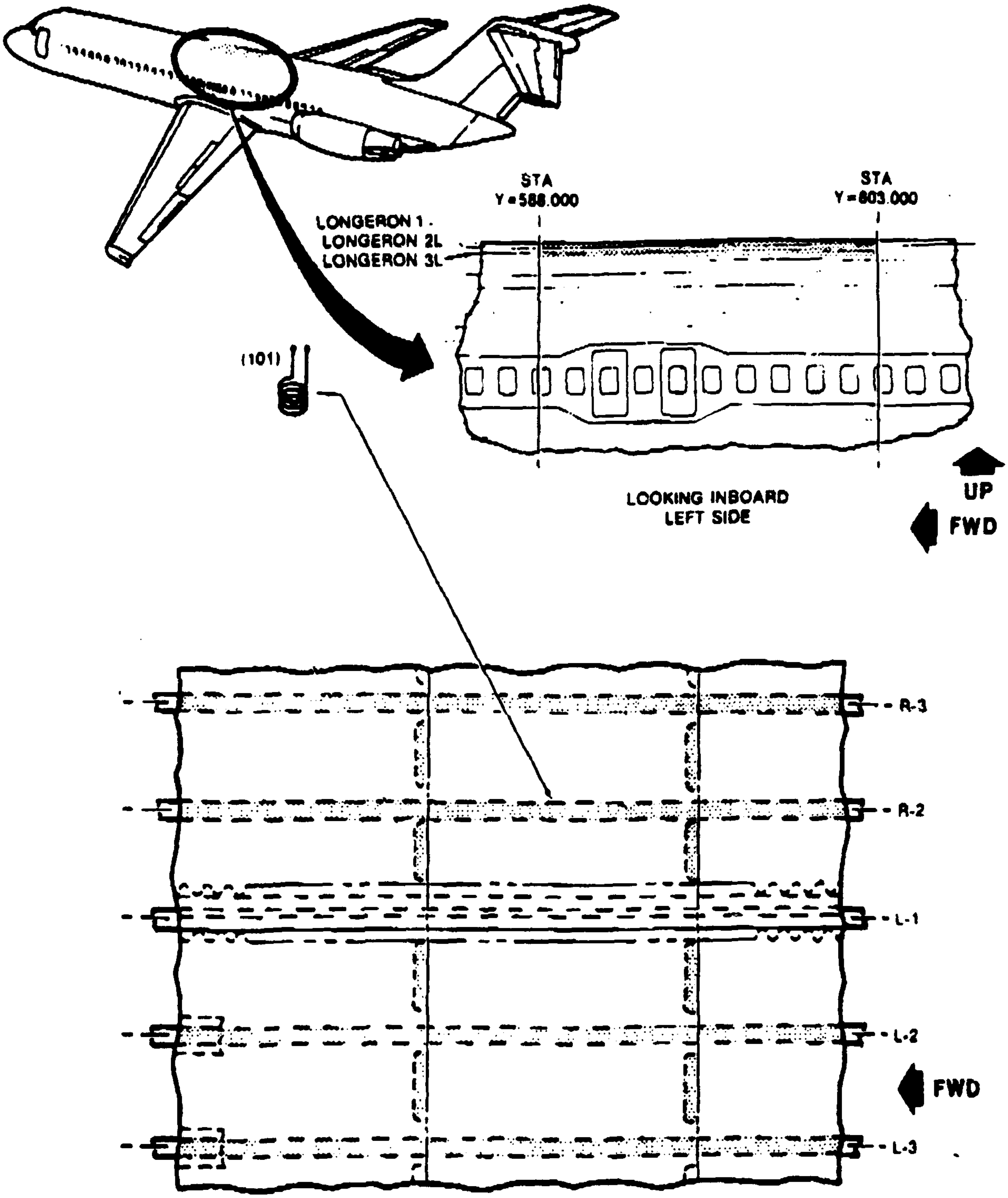


FIGURE 1. INSPECTION ITEM

FIGURE A-3. INSPECTION ITEM
Courtesy of McDonnell Douglas Corp.

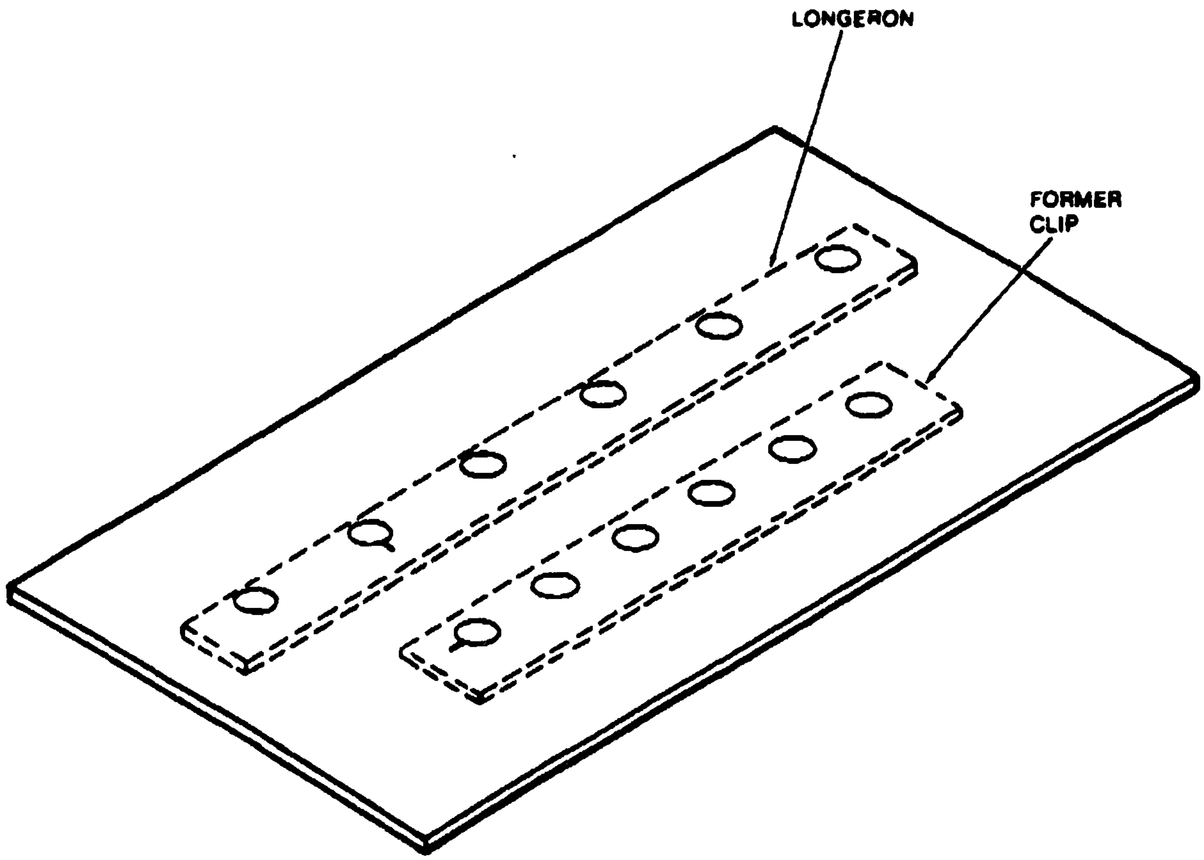
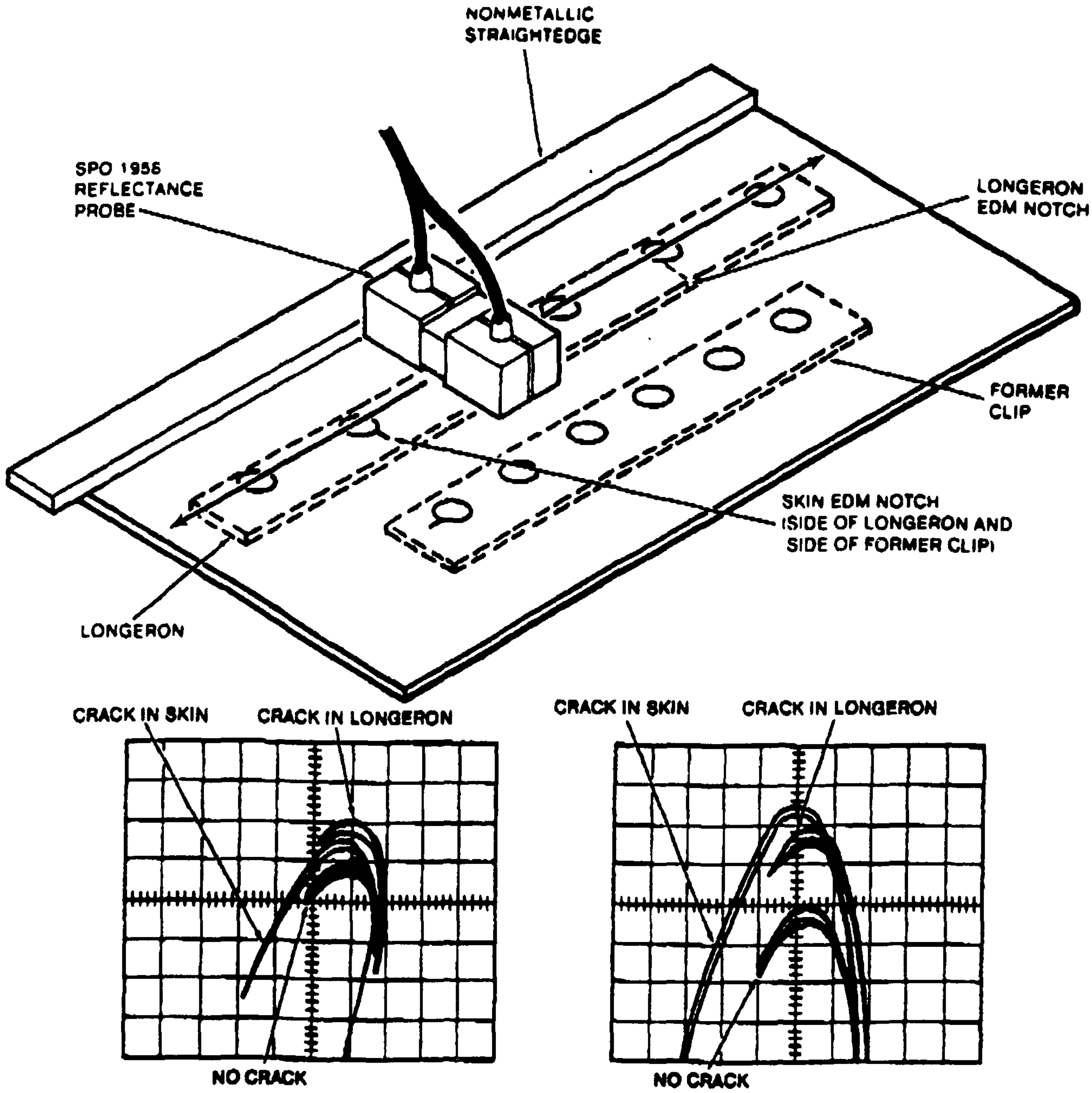


FIGURE A-4. EDDY CURRENT REFERENCE STANDARD
Courtesy of McDonnell Douglas Corp.



INSTRUMENT - NDT-18
PROBE - SPO 1958 WITH 0.3 SPACER
FREQUENCY - 2 kHz
GAIN - 40 dB
VERTICAL - 0.2
HORIZONTAL - 1.0
ROTATION - 4:00
FILTER - OFF

A. PASSENGER AIRCRAFT

NOTE:
SETTINGS LISTED WERE USED TO DEVELOP PROCEDURES. VALUES MAY VARY FROM INSTRUMENT TO INSTRUMENT.

INSTRUMENT - NDT-18
PROBE - SPO 1958 WITH 0.3 SPACER
FREQUENCY - 1.5 kHz
GAIN - 45 dB
VERTICAL - 0.2
HORIZONTAL - 0.2
ROTATION - 4:00
FILTER - OFF

B. FREIGHTER AIRCRAFT

FIGURE 8. EDDY CURRENT SCOPE PRESENTATION FOR LONGERON AND SKIN CRACK

FIGURE A-5. EDDY CURRENT INDICATIONS FOR LONGERON AND SKIN CRACK
Courtesy of McDonnell Douglas Corp.

Technique 3 - Inspection for Corrosion

1. Purpose

A. To detect and estimate corrosion loss in aluminum outer skin at faying surface of skin-doubler structures for outer skin up to 0.125 inch (0.32 cm) thick using meter signal display eddy current instruments. Calibration details are provided for clad 2024-T3 or T4 and clad 7075-T6 Aluminum alloys. Further correction would be required in the case of bare skins or different alloys and heat treatments with different base conductivity.

B. Eddy currents respond to both intergranular cracking associated with corrosion and volume loss. Therefore, this procedure cannot be used to give an exact depth of corrosion. The procedure is recommended for locating and identifying severe, moderate, or minor areas of corrosion.

C. Visual aids should be used to locate suspect areas, e.g., bulging of the skin due to corrosion product, popped fastener heads, or corrosion product around fastener heads.

2. Equipment

A. Instruments - Any eddy current instrument satisfying the requirements of this procedure is suitable for this inspection. The following instruments were used in the development of this procedure:

INSTRUMENT	MANUFACTURER
Alcoprobe MK III	Inspection Instruments (NDT) limited
Alcoprobe S	Inspection Instruments (NDT) limited
Super Halec	Hocking Electronics, Inc. Halo Instruments Division
MIZ-10 or MIZ-10A	Zetec, Inc.

B. Probes -- This procedure uses flat surface probes. Probe operating frequency is determined by thickness of test skins. In general, smaller active probe diameters are preferred because of their improved capability in estimating corrosion loss. See figure A-8 for eddy current probe recommendations.

C. Reference Standard -- Manufacture reference standard as shown in figure A-6. The material used in the standard should match the skin material used on the airplane.

3. Preparation for Inspection

A. Thick or rough paint should be lightly sanded smooth.

B. Wipe surface clean.

4. Instrument Calibration

A. Determine skin thickness on airplane and select appropriate eddy current probe.

B. Select a frequency between the two curves, designated upper and lower limit for corrosion in the skin, in figure A-7.

C. Place probe on the full upper skin thickness, on SIDE A, of the reference standard.

D. Balance the instrument per manufacturer's instructions.

E. Adjust for lift-off as follows:

Place probe on the good area of reference standard and rock the probe so that the probe to part spacings of up to 0.006 inch (0.015 cm) give no more than a 5 percent of full scale change in meter response.

F. Slide the probe over the 10 percent material loss spot face and adjust instrument sensitivity to obtain a 20 percent of full scale meter response.

G. Add an additional 0.012 inch (0.03 cm) thick non-conductive shim to the 0.004-0.008 inch (0.01-0.02 cm) shim of the reference standard to represent the faying surface adhesive.

H. Place probe over a full thickness area on the reference standard and note meter reading.

I. Remove only the 0.012 inch (0.03 cm) shim and note change in meter reading. If the difference in meter readings exceeds 10 percent of full meter scale, select a different frequency.

NOTE: Lower frequencies are more sensitive to separations between the skin and doubler and too high a frequency will not penetrate sufficiently to detect shallow amounts of corrosion.

If frequency change is required, repeat steps in par. 4.B through 4.I.

J. Reassemble the reference standard with only the 0.004-0.008 inch (0.01-0.02 cm) shim.

K. Check instrument sensitivity by sliding the probe over the surface representing the 10 percent material loss and adjusting the sensitivity to obtain a 20 percent of full scale meter response.

L. When sensitivity is adjusted properly, slide the probe over the 20 percent and 30 percent material loss spot faces, note meter response.

M. Place the probe on the skin-only portion of the standard and note the characteristic meter response as the probe is slid onto the skin-doubler portion of the standard.

5. Inspection Procedure

A. Calibrate instrument per par. 4.

B. Place probe on the skin to be inspected, in an area where there is no second layer structure and no evidence of corrosion.

C. Position meter response on scale and slide the probe onto the adjacent skin-doubler area. The instrument should respond in a manner similar to that of par. 4.M. If not, repeat check at another location to assure corrosion was not present. If response from airplane and reference standard are not approximately the same, re-check standard and airplane for similarity of skin alloy and thickness.

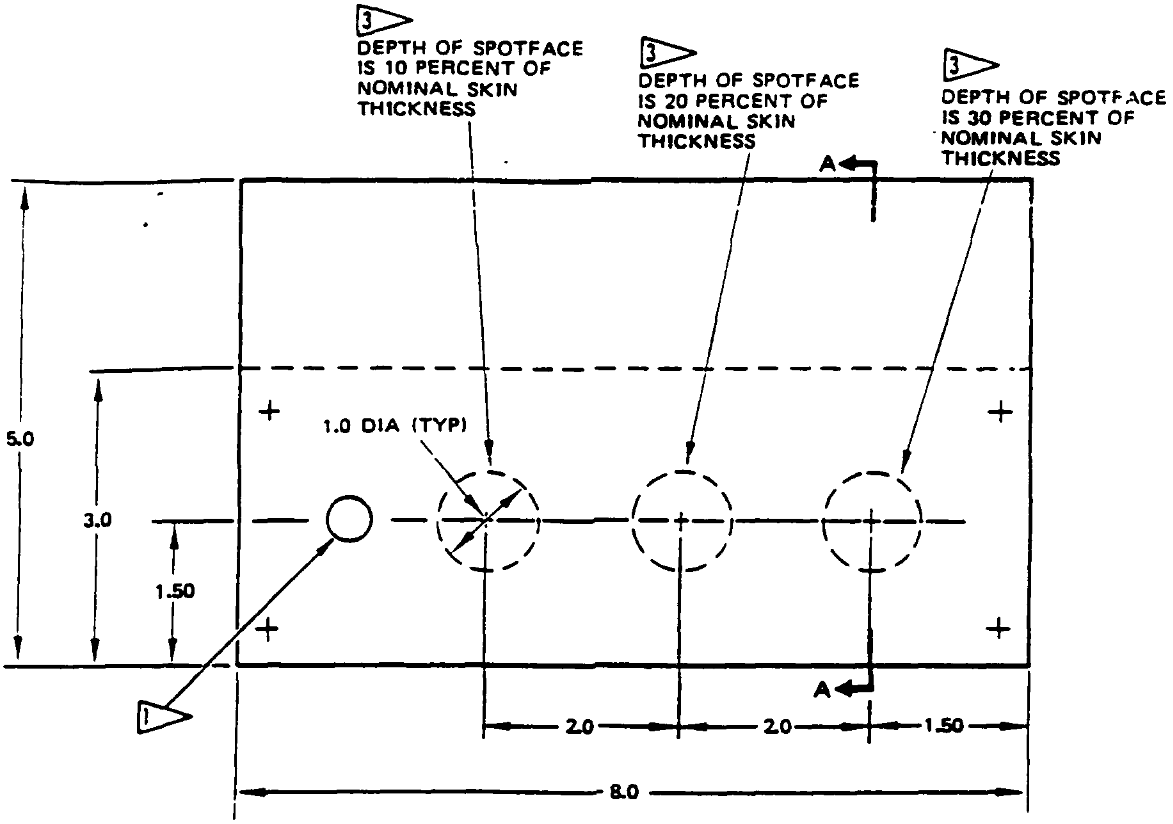
D. Place probe on good area and slide the probe into the area of suspected corrosion. Note location where the meter response is equal to or greater than the 10 percent material loss calibration response.

NOTE: A non-conductive straight-edge may be used to maintain uniform distance to the edge of the second layer structure or fasteners.

NOTE: Corrosion indications are characterized by erratic meter movement due to the intergranular corrosion, cracking, and pitting associated with corrosion.

6. Inspection Results

A. Any meter response indicating 10 percent or greater corrosion loss in suspect area should be investigated further.

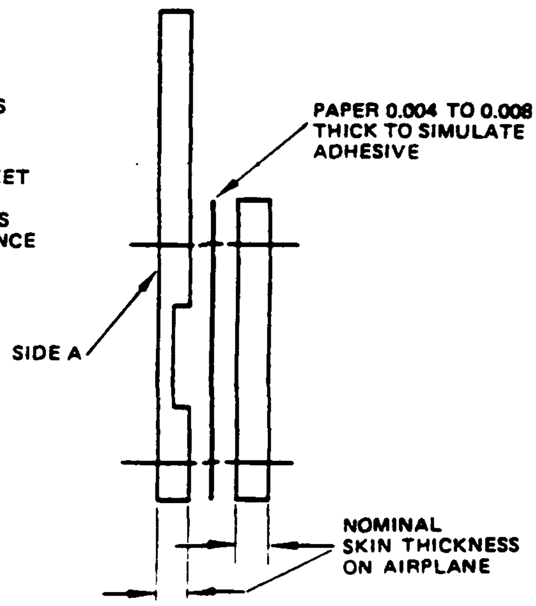


NOTES

- ALL DIMENSIONS ARE IN INCHES
- MATERIAL: CLAD 2024–T3 OR CLAD 2024–T4 SHEET
- IDENTIFY MATERIAL THICKNESS ON BOTH MEMBERS OF REFERENCE STANDARD

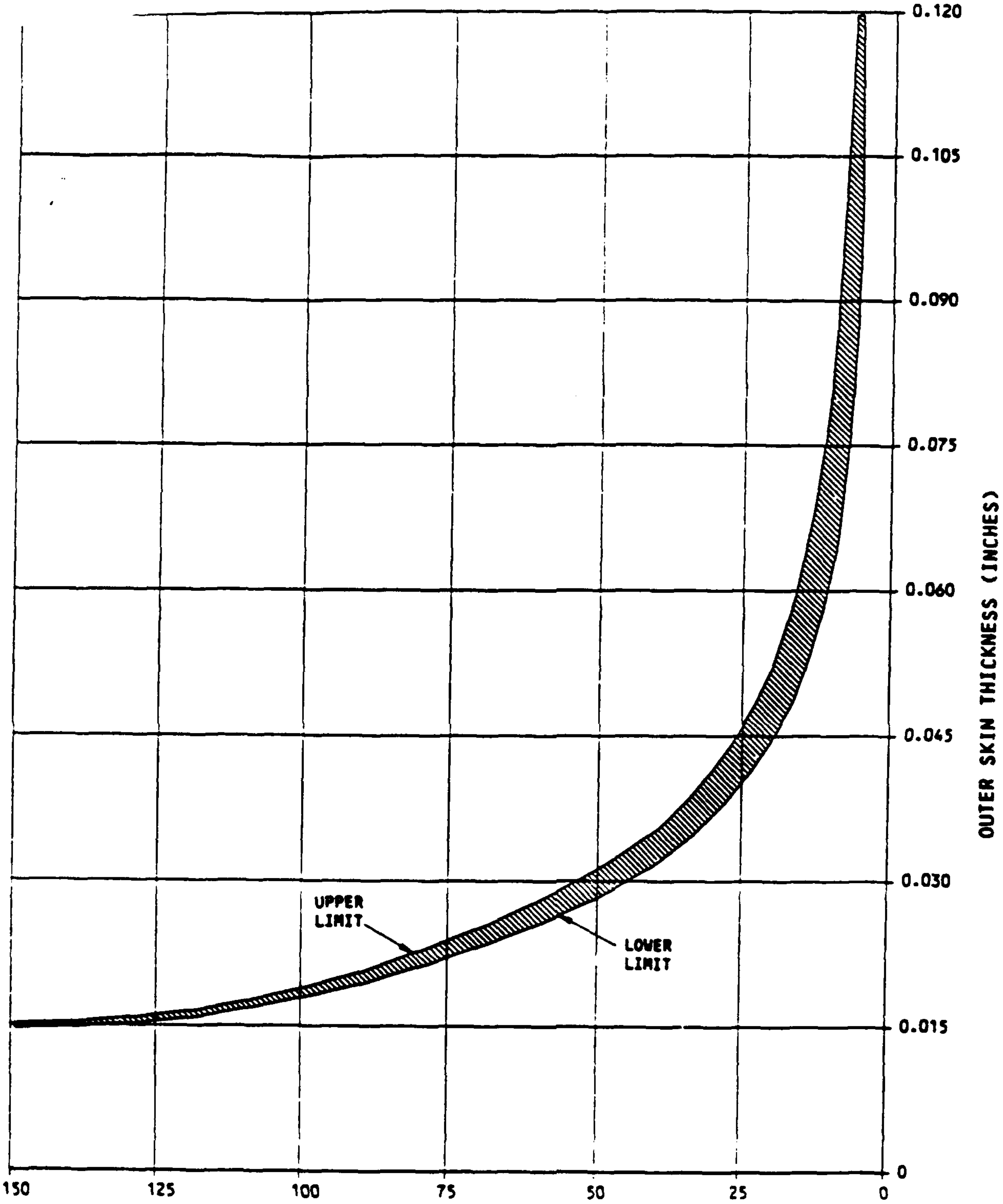
1 PROBE PLACED OVER FULL THICKNESS OF REFERENCE STANDARD

3 SPOTFACE DEPTH TOLERANCE: ± 0.001 INCH



SECTION A–A

FIGURE A-6. CORROSION REFERENCE STANDARD
Courtesy of Boeing Commercial Airplanes



FREQUENCY SELECTION LIMITS
DETAIL II

FIGURE A-7. FREQUENCY SELECTION LIMITS
Courtesy of Boeing Commercial Airplanes

PROBES USED IN THE DEVELOPMENT OF THIS PROCEDURE:

PROBE	USABLE FREQUENCY RANGE	ACTIVE PROBE DIAMETER (INCHES)	MANUFACTURER
(1) SPO 565A	500 Hz-10kHz	0.312	NORTEC
(2) SPO 1391	1 kHz-20kHz	0.218	NORTEC
(3) SPO 1598	20 kHz-50kHz	0.125	NORTEC

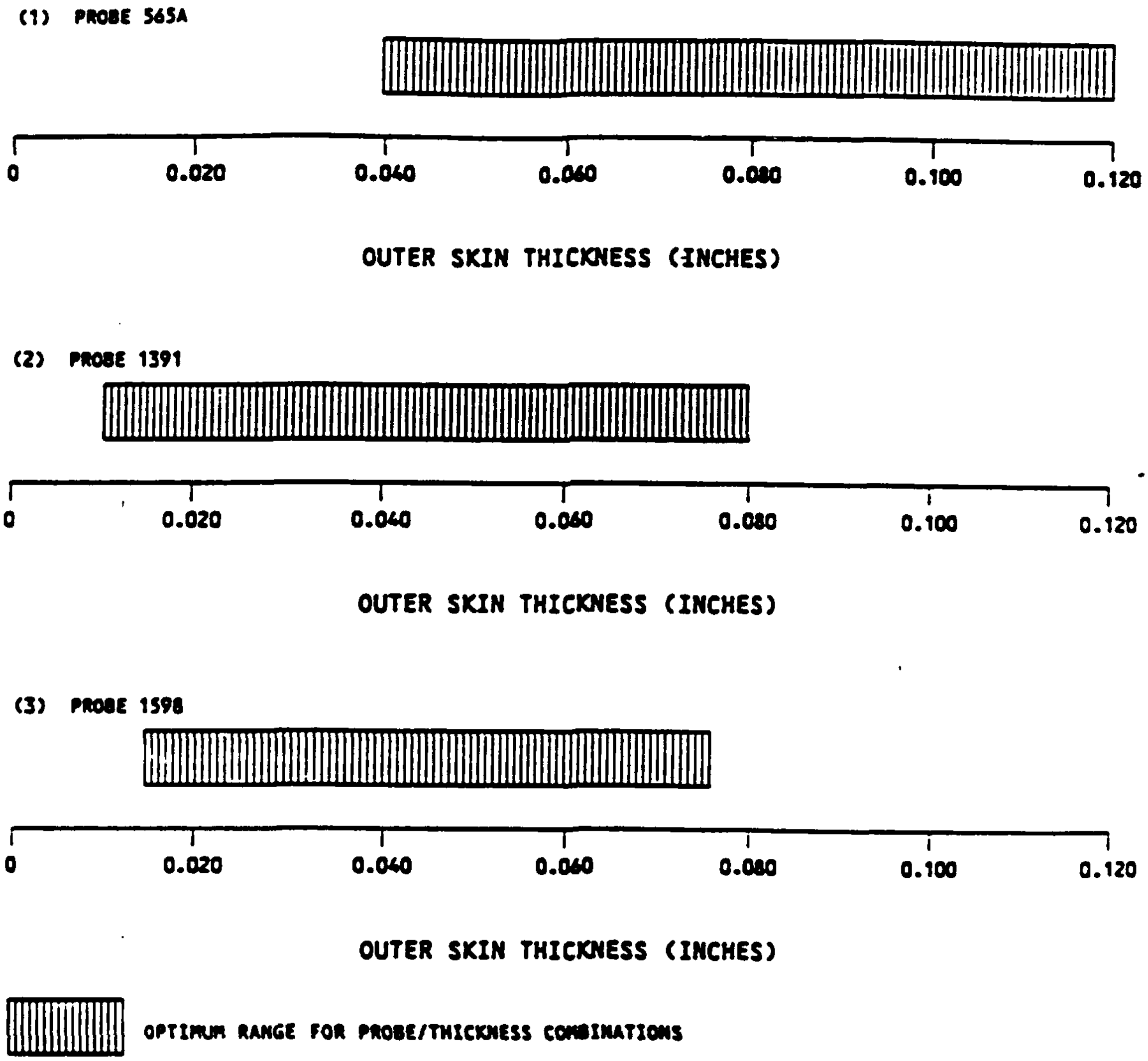


FIGURE A-8. PROBE RECOMMENDATIONS
Courtesy of Boeing Commercial Airplanes

APPENDIX B - ULTRASONIC INSPECTIONS

LIST OF ILLUSTRATIONS

Technique 1 - Inspection of Fasteners

1. Purpose

To detect broken or severely cracked bolts using ultrasonic inspection.

NOTE: This procedure cannot be used to inspect certain bolt types. For typical bolts, which may be inspected, see figure B-1.

2. Equipment

A. Instrument/Transducer -- Any pulse-echo ultrasonic instrument and transducer combination operating in the 5 to 10 MHz range, satisfying the calibration requirements of par. 4, is suitable for this procedure. The following equipment was used in developing this procedure:

1. Instrument -- USL 38, Krautkramer Branson

2. Transducer -- 0.25-inch diameter, 10 MHz, gamma, P/N 2911645-1, K. B. Aerotech

B. Reference Standard -- Calibration Bolt and Calibration Block.

1. Calibration Bolt -- Use bolt of similar material, type, and length as bolt to be examined.

2. Calibration Block -- one inch thick block of similar material as bolt to be examined.

C. Couplant -- Light grease or equivalent, compatible with airplane structure.

3. Preparation for Inspection

A. Locate inspection bolt and ensure end of bolt contacting transducer is clean and free of sealant.

4. Instrument Calibration

A. Apply couplant to calibration block and ends of calibration bolt.

B. Perform preliminary instrument adjustments per the operating manual.

NOTE: Reject or signal suppression is not to be used in calibration or inspection

C. Place transducer on calibration block. Adjust screen range to equal one major division on the screen graticule per one-inch of calibration block length.

D. Adjust instrument gain using calibration bolt for inspection conducted from:

NOTE: Transducer used for inspection should not allow more than 10 percent full screen height of spurious signals between the initial pulse and the back surface reflection at the calibration gain setting.

1. Bolt head (annulus).

   a. Place transducer firmly on flat surface of calibration bolt head (annulus).

   b. Adjust gain to obtain a back surface reflection amplitude of 40 percent of full screen height (figure B-2).

2. Bolt threaded end.

   a. Place transducer firmly on flat surface of calibration bolt threaded end.

   b. Adjust gain to obtain a back surface reflection amplitude of 60 percent of full screen height (figure B-3).

5. Inspection Procedure

A. Determine the bolt properties and the end of bolt to be inspected.

B. Calibrate instrument per par. 4.

C. Apply couplant to bolt end.

D. Place transducer firmly on flat of bolt end and scan. Screen presentation should appear as noted during calibration.

NOTE: Bolt length can be verified by comparing the length indicated by the position of the back surface reflection to the known length of the calibration bolt or block (par. 4.C.). If bolt appears to be

0.25 inch shorter or 0.50 inch longer than calibration bolt, verify length in reference drawings.

6. Inspection Results

NOTE: Ensure that transducer is placed firmly on bolt when obtaining inspection results.

A. A fracture along the shank will be noted by an indication from the fracture face with the absence of the expected back surface reflection.

B. A large crack without shank separation may be noted by an indication of 20 percent full screen height or greater, with the expected back surface reflection still visible.

C. If fracture face of bolt is irregular, the reflected ultrasound may be deflected away from the transducer. Loss of back surface reflection amplitude indicates a potential cracked or fractured bolt.

D. Compare all results to those obtained from calibration bolt (par. 4.D).

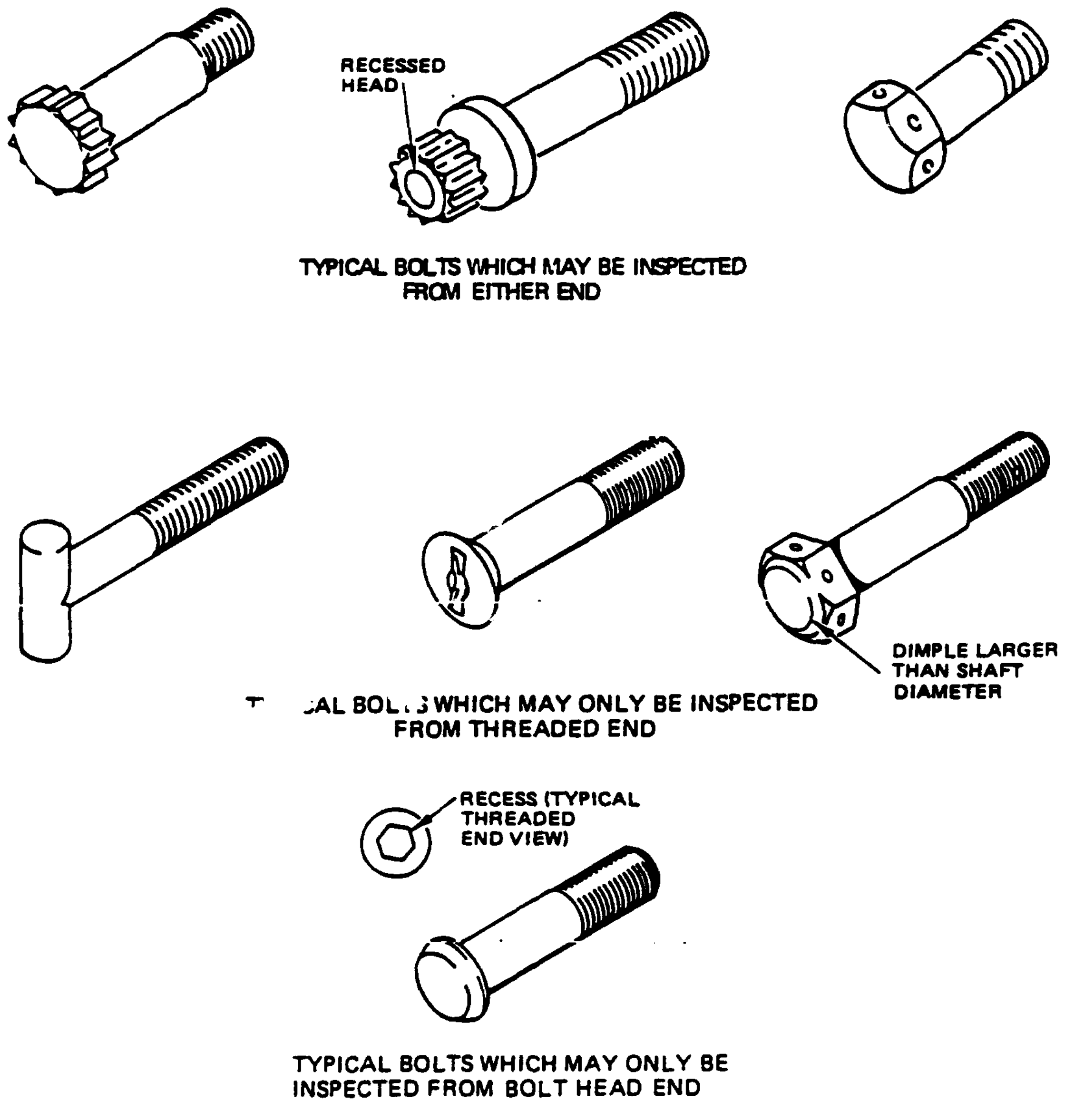
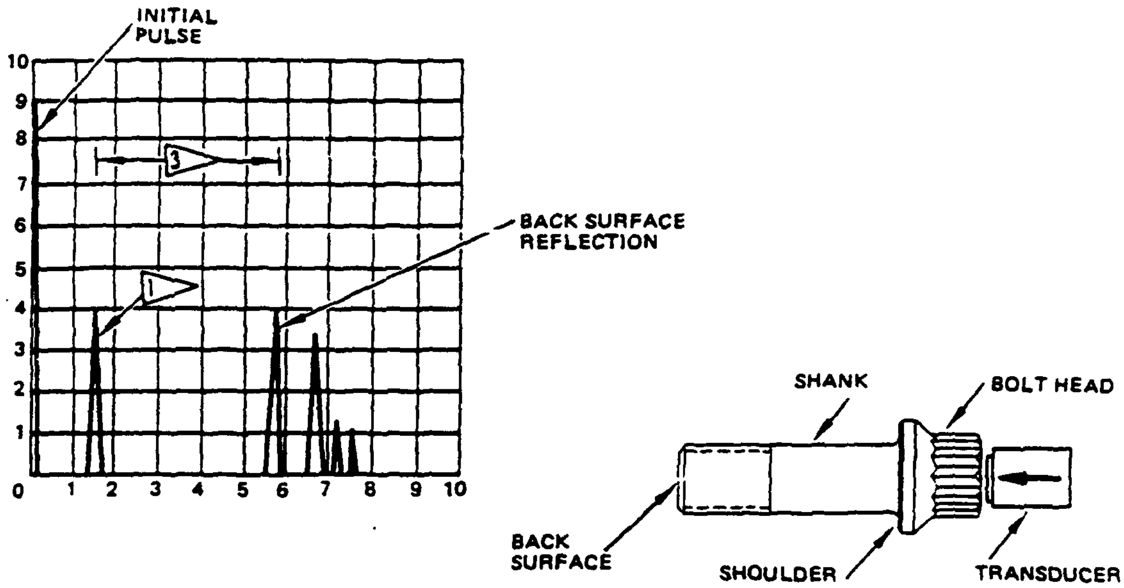


FIGURE B-1. TYPICAL BOLT TYPES
Courtesy of Boeing Commercial Airplanes



NOTES

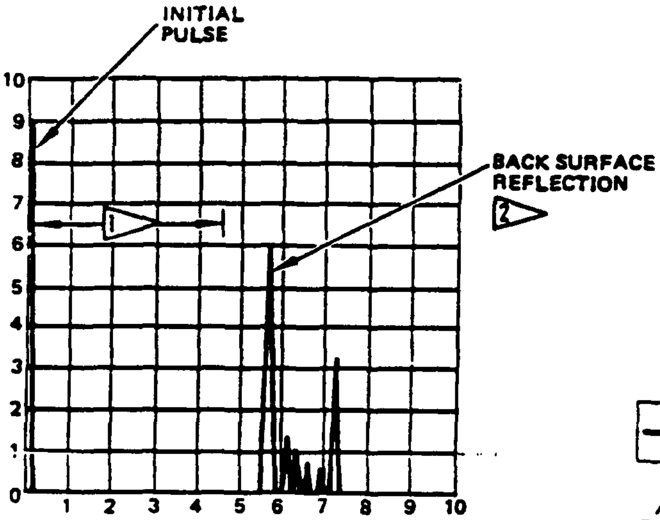
- TYPICAL SCREEN RESPONSE FOR INSPECTION CONDUCTED FROM BOLT HEAD (ANNULUS) OF A 5.5 INCH BOLT

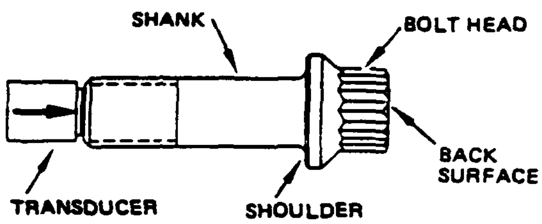
1. SIGNAL FROM BOLT SHOULDER WHEN TRANSDUCER POSITION OVERLAPS BOTH BOLT SHOULDER AND SHANK

2. BACK SURFACE REFLECTION IS FIRST SIGNAL OF RECEIVED BACK SURFACE REFLECTIONS AND IS AMPLITUDE SENSITIVE ACCORDING TO BOLT DIAMETER. SET SIGNAL AMPLITUDE TO 40% OF FULL SCREEN HEIGHT

3. TYPICAL FRACTURE OR CRACK INDICATIONS WILL APPEAR BETWEEN BOLT SHOULDER SIGNAL AND BACK SURFACE REFLECTION

FIGURE B-2. BOLT HEAD RESPONSE
Courtesy of Boeing Commercial Airplanes





NOTES

- TYPICAL SCREEN RESPONSE FOR INSPECTION CONDUCTED FROM THREADED END OF A 5.5 INCH BOLT

1. TYPICAL FRACTURE OR CRACK INDICATIONS WILL APPEAR BETWEEN INITIAL PULSE AND CALCULATED SCREEN DISTANCE OF SHANK LENGTH

2. BACK SURFACE REFLECTION IS FIRST SIGNAL OF RECEIVED BACK SURFACE REFLECTIONS AND IS AMPLITUDE SENSITIVE ACCORDING TO BOLT DIAMETER. SET SIGNAL AMPLITUDE TO 60% OF FULL SCREEN HEIGHT

FIGURE B-3. THREADED END RESPONSE
Courtesy of Boeing Commercial Airplanes

Technique 2 - Inspection of Fuselage Doublers

1. Purpose

To detect disbonding of the fuselage bonded doublers. The structure consists primarily of 0.036-inch thick 2024-T3 outer skin. The inspection is from the exterior skin side.

2. Equipment

A. Any bond inspection instrument capable of detecting disbonds 1 square inch and larger in the structure described above is acceptable. The following instruments, which do not require a liquid couplant, have been used for the inspection and found satisfactory:

1. Model S-3 Audible Bondtester, Zetec Corporation.

2. ABE (Advanced Bond Evaluator) UNIWEST Inc.

3. Model S-5 Sondicator Bondtester, Zetec Corporation.

B. Probes

1. Sondicator Contact Probe, Zetec, Inc., use with either the Sondicator Bondtester Model S-2B, Model S05 or Model S-3 Audible Bondtester.

C. Test Specimen

1. It is recommended that a bonded test specimen containing known bond voids be fabricated or procured to serve as an inspection standard and to aid in training inspection personnel. A test specimen representative of the skin thickness per figure B-4 should be obtained.

2. If a test specimen is not available, the instrument may be calibrated on a portion of the aircraft assumed to be bonded. However, since this procedure does not permit checking the level of response to voids, it is not recommended except for experienced personnel.

D. Bonded Doubler Location

1. The location of the bonded doublers (tear straps) is shown on figure B-5. This configuration is typical of the structure above stringer 10.

3. Preparation for Inspection

A. Clean loose dirt, paint flakes, or blisters from inspection surface.

B. Locate position of tear straps by the fastener pattern at lap splices.

4. Instrument Calibration

A. Turn on the bond inspection instrument and following the instrument manufacturer's instructions, check the operation of the instrument on bonded and disbonded portions of the test specimen.

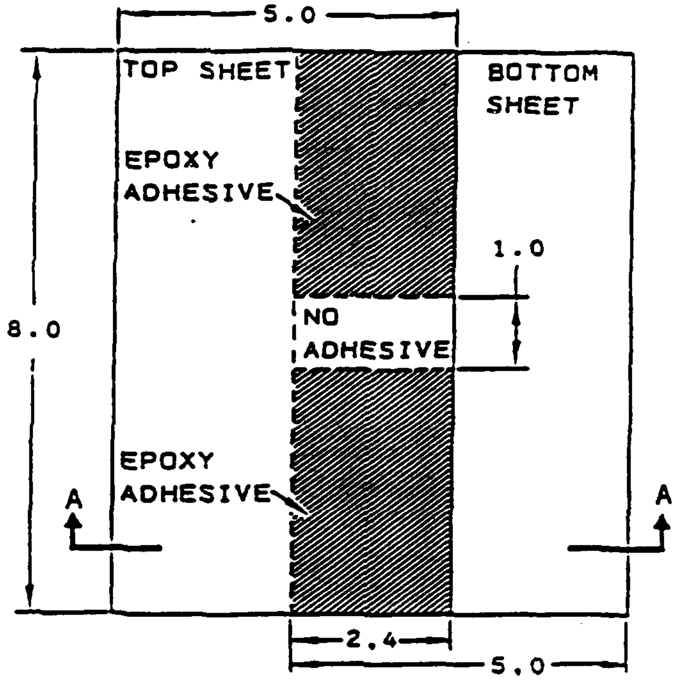
5. Inspection Procedure

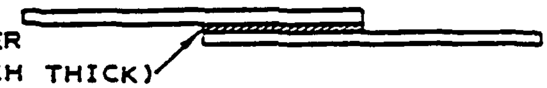
A. Use the fastener pattern just above the longitudinal lap joints to locate the location of the doublers.

B. Place the probe on the fuselage skin away from the doubler. The instrument should give a single thickness (disbond) indication.

C. Slide the probe either fore or aft across a bonded doubler. The instrument should give a bonded indication as the probe passes across the bonded area.

D. Inspect the bonded doublers (tear straps) by sliding the probe back and forth across the doubler locations.





SECTION A-A

NOTES

- ALL DIMENSIONS ARE IN INCHES.
- ANY EPOXY ADHESIVE MAY BE USED. IT IS SUGGESTED THAT THE ADHESIVE LAYER BE 0.004 TO 0.005 INCH THICK FOR ADEQUATE STRENGTH.
- MATERIAL: TOP AND BOTTOM SHEETS 2024-T3 OR 7075-T6 CLAD ALUMINUM.
- 737 BONDED TEST SPECIMENS ARE FABRICATED WITH BOTH TOP AND BOTTOM SHEETS OF 0.036 OR 0.040 INCH THICK CLAD ALUMINUM.
- TEST SPECIMENS ARE AVAILABLE FROM:

IDEAL SPECIALITY COMPANY NDT PRODUCT ENGINEERING

FIGURE B-4. ADHESIVE BOND TEST SPECIMEN
Courtesy of Boeing Commercial Airplanes

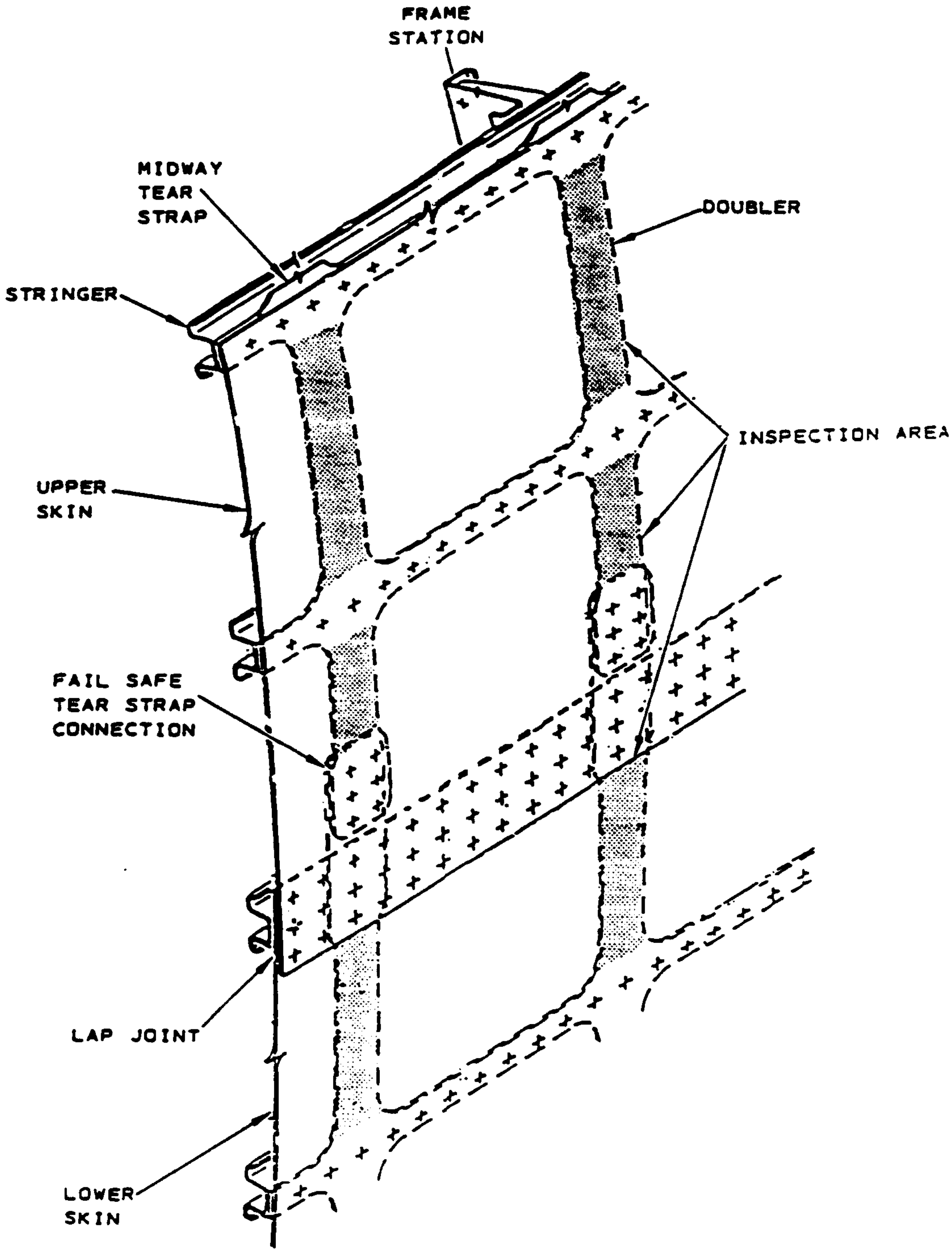


FIGURE B-5. TYPICAL BONDED DOUBLER CONFIGURATION
Courtesy of Boeing Commercial Airplanes

APPENDIX C - RADIOGRAPHIC INSPECTIONS

LIST OF ILLUSTRATIONS

Technique 1 - Door Jamb Inspection

1. <u>Purpose</u>

A. This inspection is performed to detect fatigue cracks in the skin and/or doublers below the door jamb repair plate.

2. <u>Radiographic Check (See Figures C-1 through C-3)</u>

A. Test Equipment and Materials Required

Name	Type and Number
Portable X-ray or equivalent.	Sperry SPX160 (1.5mm projected focal spot)
X-ray Film	Type 1 and 2
Film Size	Kodak AA or equivalent, enough film to cover repair area. Kodak M or equivalent, enough film to cover repair area.

B. Preparation for Inspection

1. Clean area around door jamb of all grease and dirt.
2. Remove scuff plate if covering inspection area.
3. Mark area for proper film positioning.

C. Inspection Procedure

<u>WARNING</u>: A. USE OF RADIATION IN NONDESTRUCTIVE TESTING PRESENTS POTENTIAL HAZARDS TO ALL PERSONNEL IN THE AREA. OBSERVE ALL RADIATION SAFETY REQUIREMENTS WHEN OPERATING X-RAY EQUIPMENT.

<u>WARNING</u>: B. TO AVOID INJURY TO PERSONNEL OR DAMAGE TO EQUIPMENT, ADEQUATE PRECAUTIONS MUST BE TAKEN WHILE PERFORMING ANY WORK IF ELECTRICAL POWER IS APPLIED TO THE AIRCRAFT.

<u>CAUTION</u>: A. ELECTRICALLY GROUND THE AIRCRAFT.

B. USE APPROPRIATE RIGGING AND PLATFORMS AND/OR MANLIFT IN ORDER TO POSITION THE FILM AND HOLD THE PORTABLE TUBE-HEAD IN PLACE.

1. Prepare I.D. tag and attach to film pack.

2. Attach film to backside of area to be inspected.

3. Position x-ray source according to details in figure C-1.

4. Expose film in accordance with x-ray parameters detailed in figures C-2 and C-3.

5. Process and interpret film.

D. Post Inspection Procedure

1. Remove any tape left on aircraft.

2. Remove and secure all test equipment and materials from the area.

E. Disposition

1. Report all inspection results, cracked or uncracked. Any indication of a crack is unacceptable.

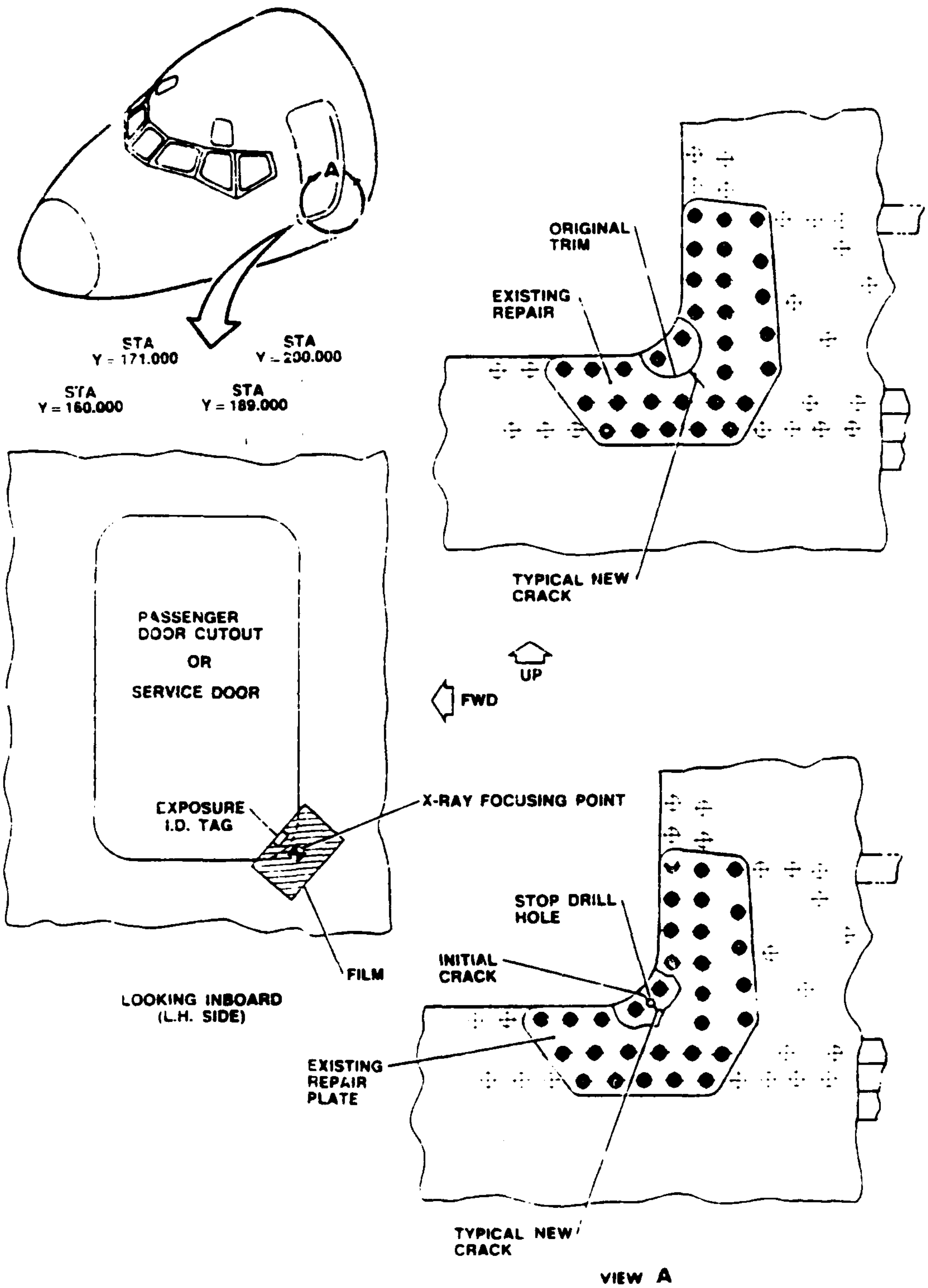
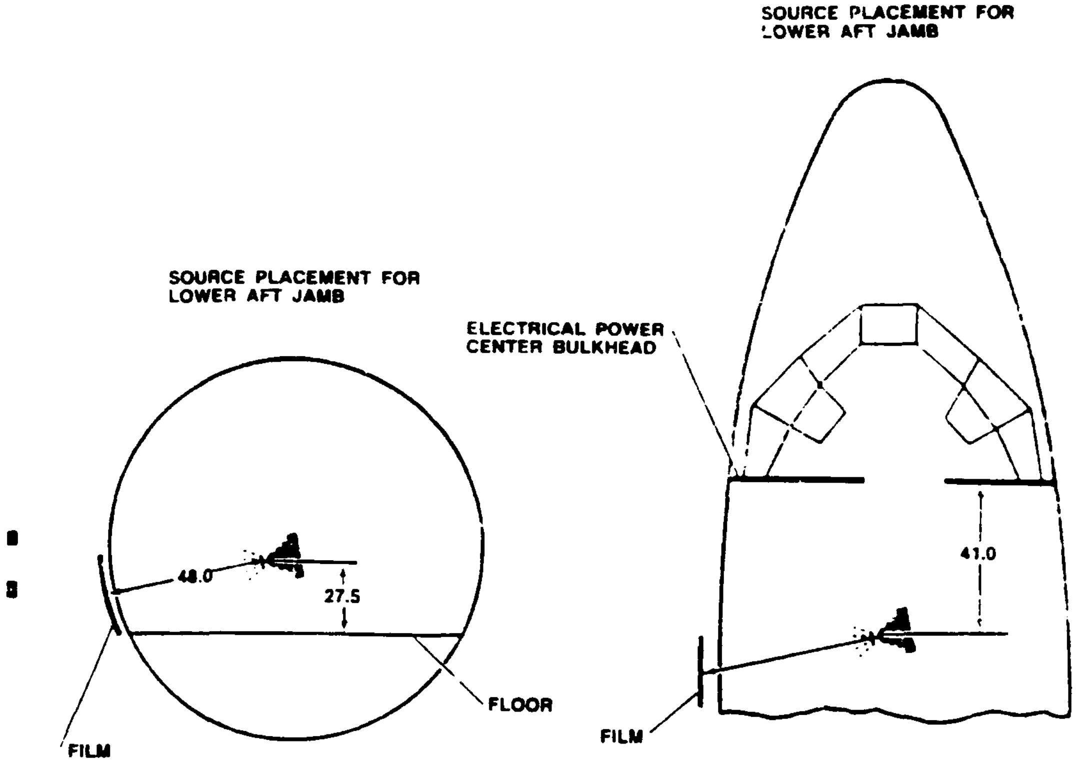


FIGURE C-1. DOOR JAMB REPAIR PLATE
Courtesy of McDonnell Douglas Corp.

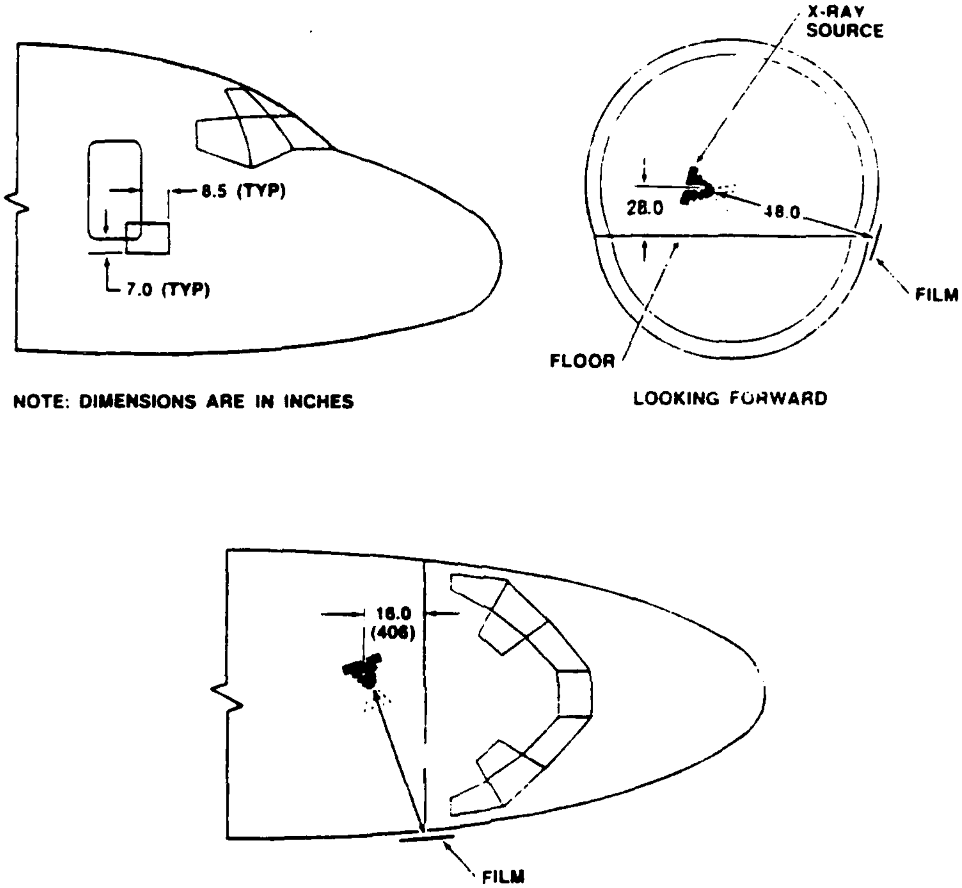


NOTE:
DIMENSIONS ARE IN INCHES.

EXPOSURE NO.	SUBJECT	kV*	mas*	SFD (INCH)	FILM TYPE	FILM SIZE (INCH)	REMARKS
1	LOWER AFT JAMB CORNER	100	425	48	1 AND 2	**	REPAIR SHOWN IN SRM 53-05, PAGE 16. MAY BE FOUND ON OTHER DOORJAMBS

*ADJUST AS NECESSARY TO OBTAIN A FILM DENSITY OF 1.5 TO 3.0 H&D UNITS.
**FILM SHOULD BE LARGE ENOUGH TO COVER INSPECTION AREA.

FIGURE C-2. RADIOGRAPHIC INSPECTION OF PASSENGER DOOR JAMB REPAIR PLATE
Courtesy of McDonnell Douglas Corp.



EXPOSURE NO.	SUBJECT	kV*	mas*	SFD (INCH)	FILM TYPE	FILM SIZE (INCH)	REMARKS
1	LOWER FWD JAMB PLATING	100	425	48	1 AND 2	14 X 17	

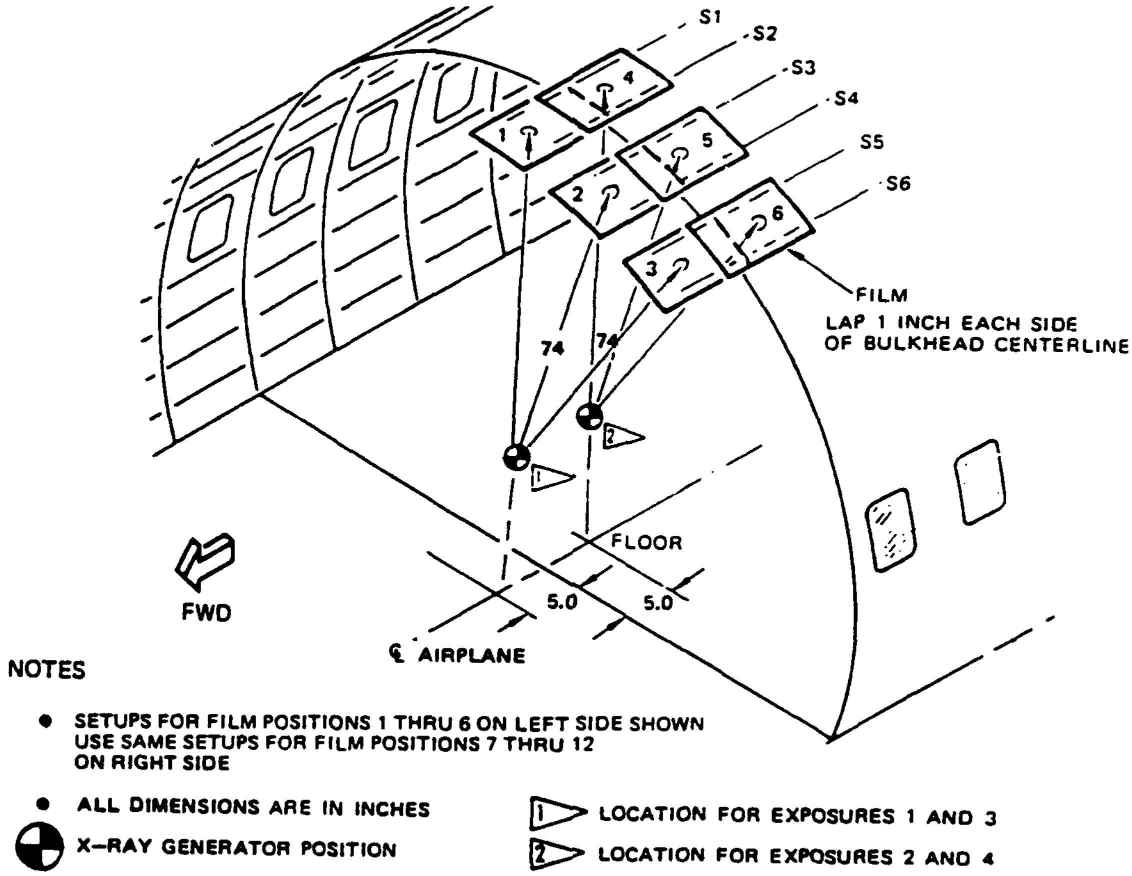
*ADJUST AS NECESSARY TO OBTAIN A FILM DENSITY OF 1.5 TO 3.0 H&D UNITS.

FIGURE C-3. RADIOGRAPHIC INSPECTION OF SERVICE DOOR JAMB REPAIR PLATE
Courtesy of McDonnell Douglas Corp.

Technique 2 - Skin And Splice Inspection

1. Purpose

A. To detect cracks in stringers, stringer splices and skin splices in the crown area (stringers S6 and above, left and right sides) at BS 360, 540, 663, 727, and 908 (see figure C-4).



X-RAY PARAMETERS						
EXPOSURE NUMBER	FILM			SFD	GENERATOR SETTINGS	
	POSITION	ASTM CLASS	SIZE		KV	MAS
1	1 THRU 3	I	14X17	74	150	1260
2	4 THRU 6	I	14X17	74	150	1260
3	7 THRU 9	I	14X17	74	150	1260
4	10 THRU 12	I	14X17	74	150	1260

FIGURE C-4. X-RAY GENERATOR AND FILM POSITIONING
Courtesy of Boeing Commercial Airplanes

[End of procedure]

☆U.S. GOVERNMENT PRINTING OFFICE: 1992 - 604-061/60141